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GEMINI ONE-TON AMPHIBIOUS OFF-HIGHWAY AIR-TRANSPORTABLE VEHICLE-CONTINUATION OF PHASE I PROGRAM

By

F. H. Keast

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February 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES

FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-21(T)

HAWKER SIDDELEY CANADA LTD.

ENGINEERING DIVISION

TORONTO, ONTARIO

U. S. ARMY MATERIEL COMMAND

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This report presents the results of the second phase of an exploratory development program to investigate the feasibility of an air cushion assist concept. The contents have been reviewed by the U. S. Army Aviation Materiel Laboratories and are considered to be technically sound. The report is published for the exchange of information and the stimulation of ideas.

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USAAVLABS Technical Report 65-83
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GEMINI ONE-TON AMPHIBIOUS OFF-HIGHWAY AIR-TRANSPORTABLE VEHICLE - CONTINUATION OF PHASE I PROGRAM

Final Report

by

F.H. Keast

Prepared by

Hawker Siddeley Canada Ltd.
Engineering Division
Toronto, Ontario

for

U.S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

ABSTRACT

This report presents the further results of testing a full-scale mock-up chassis representative of a 1-ton, amphibious, off-highway, air-transportable vehicle which utilizes air cushion principles to permit mobility in low-bearing terrain.

The test vehicle was modified and subjected to tests in water. A skirt was fitted and the vehicle was tested in prepared clay beds of low cone index and on a level, hard surface. Noise level tests were also carried out. Further work to improve directional control and speed in water and to improve skirt structure is recommended to attain optimum performance.

PREFACE

The work described in this report was carried out by Hawker Siddeley Canada Ltd., Engineering Division during the period from June 1964 to August 1965. The principal engineering members of this organization involved in the project were as follows:

Mr. F.P. Mitchell, Vice-President, Hawker Siddeley Canada Ltd.
Mr. C.A. Grinyer, Vice-President, Engineering
Mr. F.H. Keast, Director of Research
Mr. D.H. Parker, Engineering Laboratories Manager
Mr. R.F.C. Tanner, Chief Engineer, Engineering Division
Mr. R.G.A. Chisholm, Engineer
Mr. N.B. Herbert Engineer
Mr. W.U. Shaw, Senior Engineer

Acknowledgement is also made of the assistance rendered by the following members of the Organic and Associated Terrain Research Unit of McMaster University, Hamilton, Ontario.

Dr. N.W. Radforth, Chairman
Prof. W.R. Newcombe
Mr. K. Ashdown

This is the final report on the continuation of the Gemini Phase I Program and was prepared by Mr. F.H. Keast.

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ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

SUMMARY

This report presents the results of further testing of a full-scale mock-up chassis representative of a 1-ton amphibious off-highway air-transportable vehicle which utilizes air cushion principles to permit mobility in low-bearing terrain otherwise impassable to a wheeled vehicle. It follows upon, and should be read in conjunction with, TRECOM Technical Report 64-34, dated July 1964, entitled "Gemini 1-Ton, Amphibious, Off-Highway, Air-Transportable Vehicle - Concept Evaluation Program - Final Report".

The air diffusion structure in the test platform was modified and the vehicle was subjected to tests in water. The vehicle was then modified by the addition of a skirt and tested on a level, hard surface to measure air cushion lift as a function of height and in a prepared clay bed of low cone index to measure mobility. A noise level test program was also conducted.

The "paddle wheel" performance of the wheels was measured in waterborne testing. Application of air cushion during these tests increased vehicle speed. Because of inadequate directional control in water, examination of the use of direct air blast for propulsion and maneuvering is recommended.

Performance in the clay bed was not as good as during previous tests conducted without the skirt, probably because the skirt material had insufficient flexibility, causing some dragging, particularly at skirt corners. However, base pressures recorded during tests were comparable to those recorded without the skirt. A further program of skirt development is recommended to overcome the problem of inflexibility.

CONCLUSIONS AND RECOMMENDATIONS

Waterborne testing demonstrated that the use of wheels alone for water propulsion was inadequate for good directional control and speed. However, it is apparent that the considerable energy potential available in the air cushion system could be partially or completely directed as a jet stream to propel the test platform forward or backward. Preliminary calculations indicate that thrusts in the neighborhood of 200 pounds could be developed by a suitable exit nozzle at the end of the vehicle. Directional control could be achieved by deflecting the jet stream or by a conventional rudder. For the final, articulated vehicle, directional control by jet stream and vehicle articulation alone could be adequate. It is recommended that an engineering, manufacturing and test program be undertaken to modify the test platform and further examine water propulsion and directional control optimization.

Since the final vehicle will be articulated with front and rear portions incorporating separate air cushions, variations in loading will affect longitudinal balance. Design and manufacture of an experimental test installation for application to the current test vehicle to determine effectiveness of balancing means for front and rear air cushions are recommended, concurrent with the work suggested above for an air propulsion system.

Although adequate base pressures were obtained with the skirt presently installed, investigation of other skirt designs and development of the optimum skirt configuration to overcome deficiencies in the present skirt structure are desirable to attain optimum vehicle performance. Such investigation should place particular emphasis on skirt flexibility in arriving at the optimum configuration, it being established that the field problem of dragging in wet clay adversely affects mobility to a significant degree.

Although limited in scope, this program has proved to be effective in establishing practical design parameters and attention factors relative to water propulsion and terrain mobility of value to any ensuing major development program.

DISCUSSION

INTRODUCTION

A proposal was made in November 1963 to USATRECOM* and the Canadian Dept. of Defence Production by Hawker Siddeley Canada Ltd. for continuation of the Phase I program for construction of a 1-ton amphibious off-highway air-transportable vehicle.

This document is the final report on this continuation of the Phase I program and follows upon TRECOM Technical Report 64-34 dated July 1964, entitled "Gemini 1-Ton, Amphibious, Off-Highway, Air-Transportable Vehicle - Concept Evaluation Program - Final Report".

Continuation of the Phase I program commenced in June 1964, with the object of more nearly establishing certain elements of the configuration of the Phase II vehicle before this latter phase was begun. The work required to arrive at this end was contractually defined in Schedule "D1" Statement of Work, which forms part of the amended contract for the Phase I continuation program.

Subsequent pages contain a detailed report on the continuation of the Phase I program, categorized as follows:

(a) Modifications to the test vehicle (including skirt design, development, manufacture).

(b) Test results.

MODIFICATIONS TO TEST VEHICLE

General

Prior to commencement of the continuation of the Phase I program, the vehicle was cleaned up both inside and outside, the fan assembly was removed to facilitate splitter modification, and the hydraulic motors were removed, overhauled and replaced.

Power Plant

In July 1964, new plugs, points and high-tension leads were fitted to the engine at the commencement of the continuation of Phase I program and

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the engine was brought to optimum operating condition. In July 1965, difficulties with the fuel injection system were overcome by servicing components of the fuel system.

Drive Train

Small modifications were made to the fan drive train to eliminate oil leakage.

Ducting

The splitter was re-designed to facilitate varying mass flow distribution to forward and rear ducting. The re-design involved elimination of the cylindrical splitter and its radial supports as far as possible, and fitment of a streamlined plastic leading edge at the point where division of flow occurred for front and rear cushions. A comparison of the original configuration and the modified configuration is shown in Figure 1. Additional jet gates were fabricated for mass flow tests to enable a range of flow divisions to be studied.

Skirt

An engineering investigation of skirt extensions was commenced in June 1964. Available literature was studied and discussions were held with personnel of the National Aeronautical Establishment at Ottawa. To assist in establishing design, sketches were issued covering a quarter scale model of the jet platform, to be made of wood. Model skirts of various depths could be fitted to this model. Air was to be supplied from the shop service, the required low-pressure mass flow being attained by using an injector nozzle. Ground plane was to be represented by a rolling platform to which obstacles could be attached for passing through the skirt walls (see Figure 2). Four versions of possible skirt construction were drawn up covering plenum and extended jet types.

In August 1964, a proposed design of skirt construction was issued for sample manufacture in scale form. This design was of the plenum type incorporating a single extension sheet of rubber, reinforced by internal rubber gussets. Other design proposals for skirt construction were laid out, giving consideration to installation on the test and prototype vehicles.

In the following month, the ribbed plenum model was fabricated, but was held in abeyance pending tests of inflated types. Two configurations were proposed. The first consisted of a single circular inflated bag attached

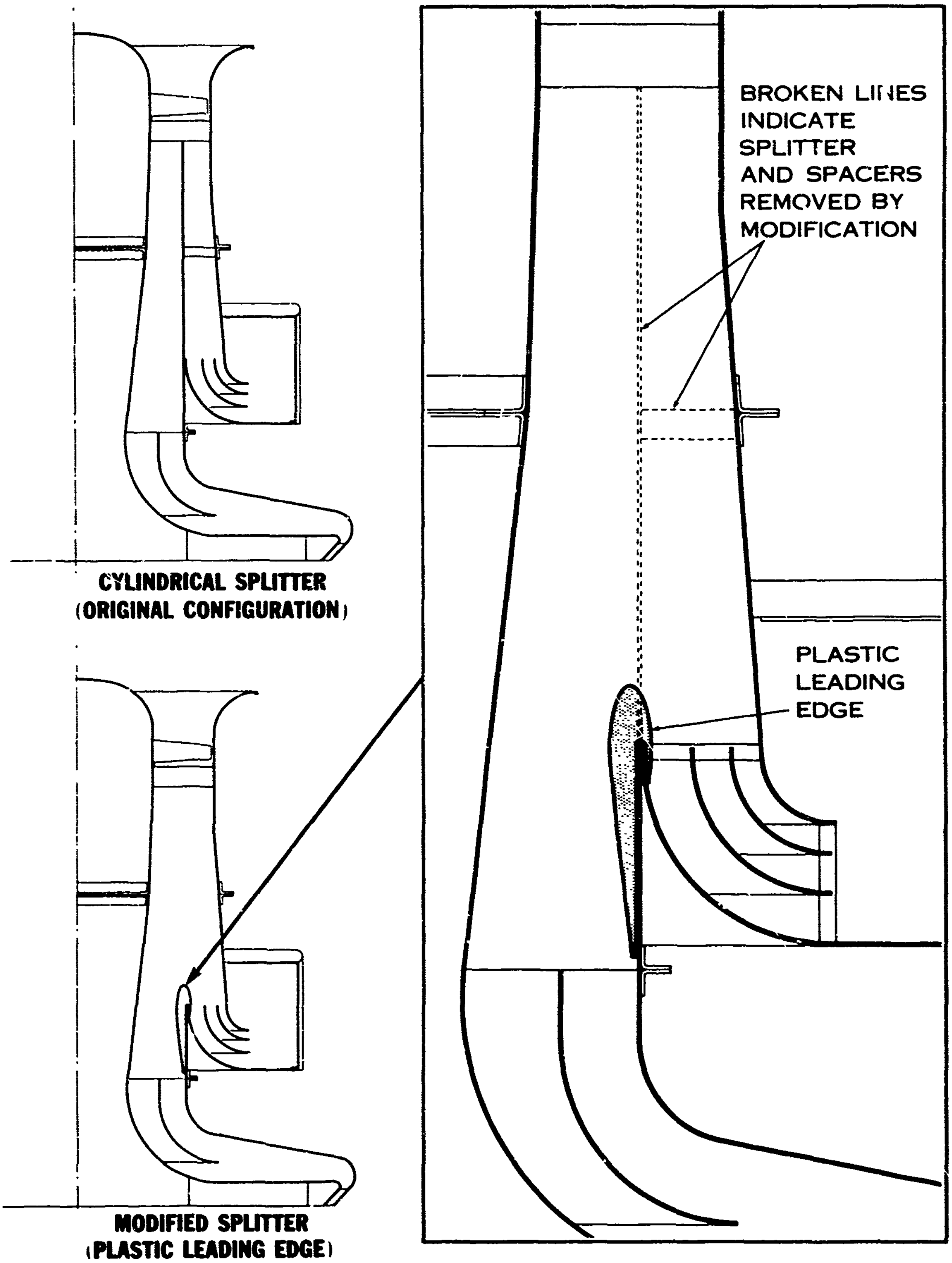


Figure 1. Comparison of Original and Modified Splitter Configurations.

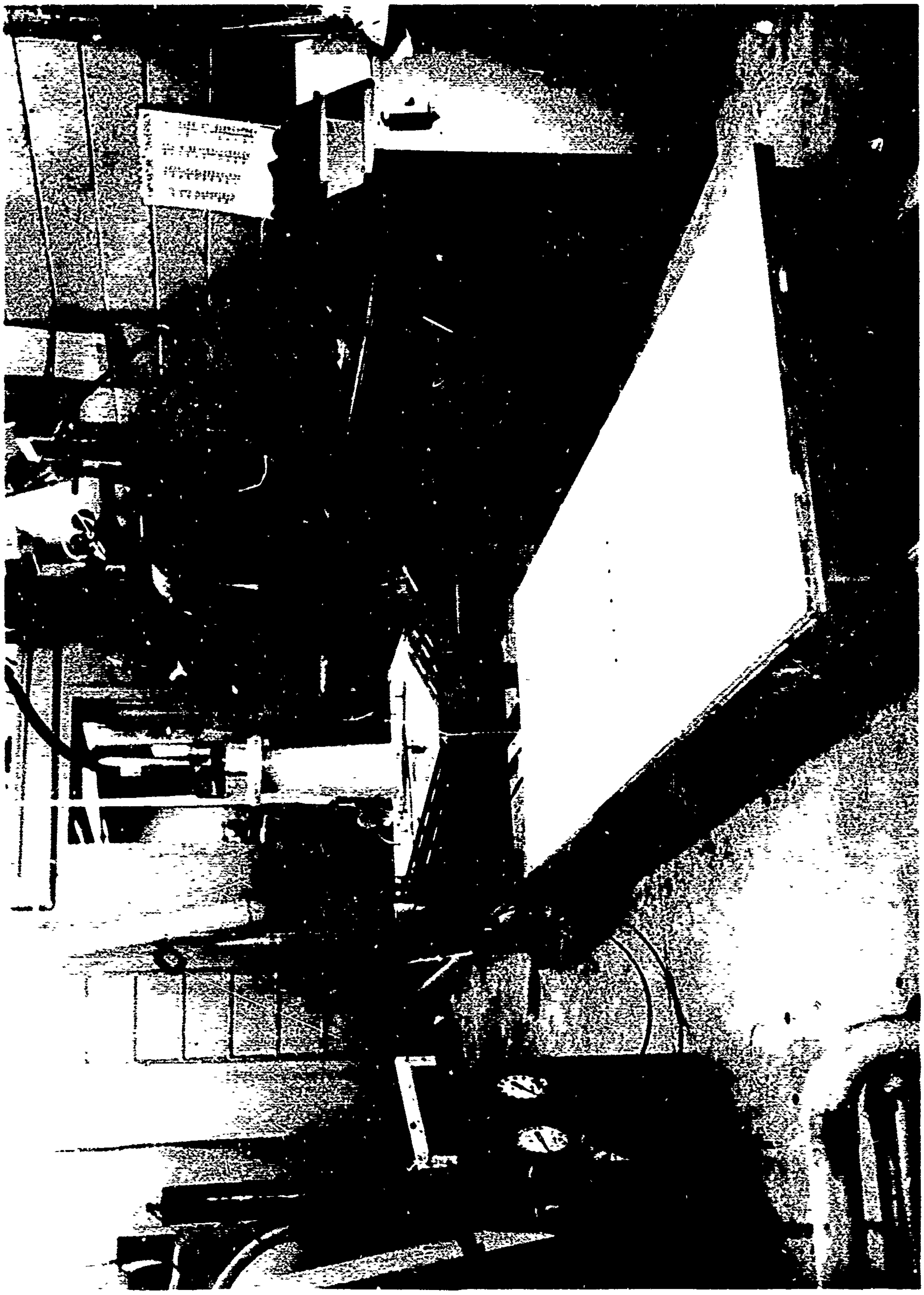


Figure 2. Skirt Model Test Rig.

to the cushion base across a short chord. The alternative design comprised a "double cylinder" with a tension web separating the two cylinders. This latter type, although of the same depth as the single type, was somewhat narrower, thus providing a larger ground cushion area.

Three-foot lengths of these two models were set up on a test box. The cylindrical type was tested with various gaps from 0.1 to 0.5 inch. Figure 3 shows the underside of the three-sided test box, the cylindrical skirt forming the fourth side. Static pressure holes can be seen in the baseboard, and the tube visible is connected to a static hole to measure ejector output pressure. Air enters through the peripheral slot from the ejector overhead. Inflation pressure was varied from 0.5 to 1.0 p.s.i. Under all conditions the skirt vibrated at a large amplitude. It was believed that this was caused by the flow breaking away alternately from the smooth ground board and the curved surface of the skirt. To check this, a 1/2-inch fence was attached to the ground board to locate the flow breakaway at the fence. This eliminated the vibration. The "double bubble" type was next tested, and substantially identical results were obtained.

For these models with a continuous lower surface, the outflowing air was markedly influenced by a Coanda effect and in some cases turned through a full 90 degrees so that it was directed upwards from the ground.

Both models were then modified to incorporate a rubber spoiler on the bottom, and were again tested. The spoiler effectively eliminated the Coanda effect and oscillations of the "double bubble" type, but the single circular type still oscillated intermittently. Both models deflected laterally by an excessive amount, at the same time increasing the gap height. Attempts to pass obstacles, which were 1/3 of the skirt depth, through the skirt, failed. The skirt was too flexible laterally but too stiff to pass over an obstruction.

Since one of the objectives was to investigate retraction of the skirt, the circular section skirt was tested with air evacuated. Left free, it collapsed into a vertical shape. When the bottom was supported, it collapsed into a horizontal shape. Undoubtedly, if a space had been available above the attachment plane, it could have been made to collapse into this; however, the bulkheads would produce a bulge when retracted. During the model building and testing periods, layouts were made of the application of each type design to the test vehicle and to a Phase II vehicle.

Design work and testing continued on skirt configurations during October 1964. It was decided to modify the original ribbed plenum model (which

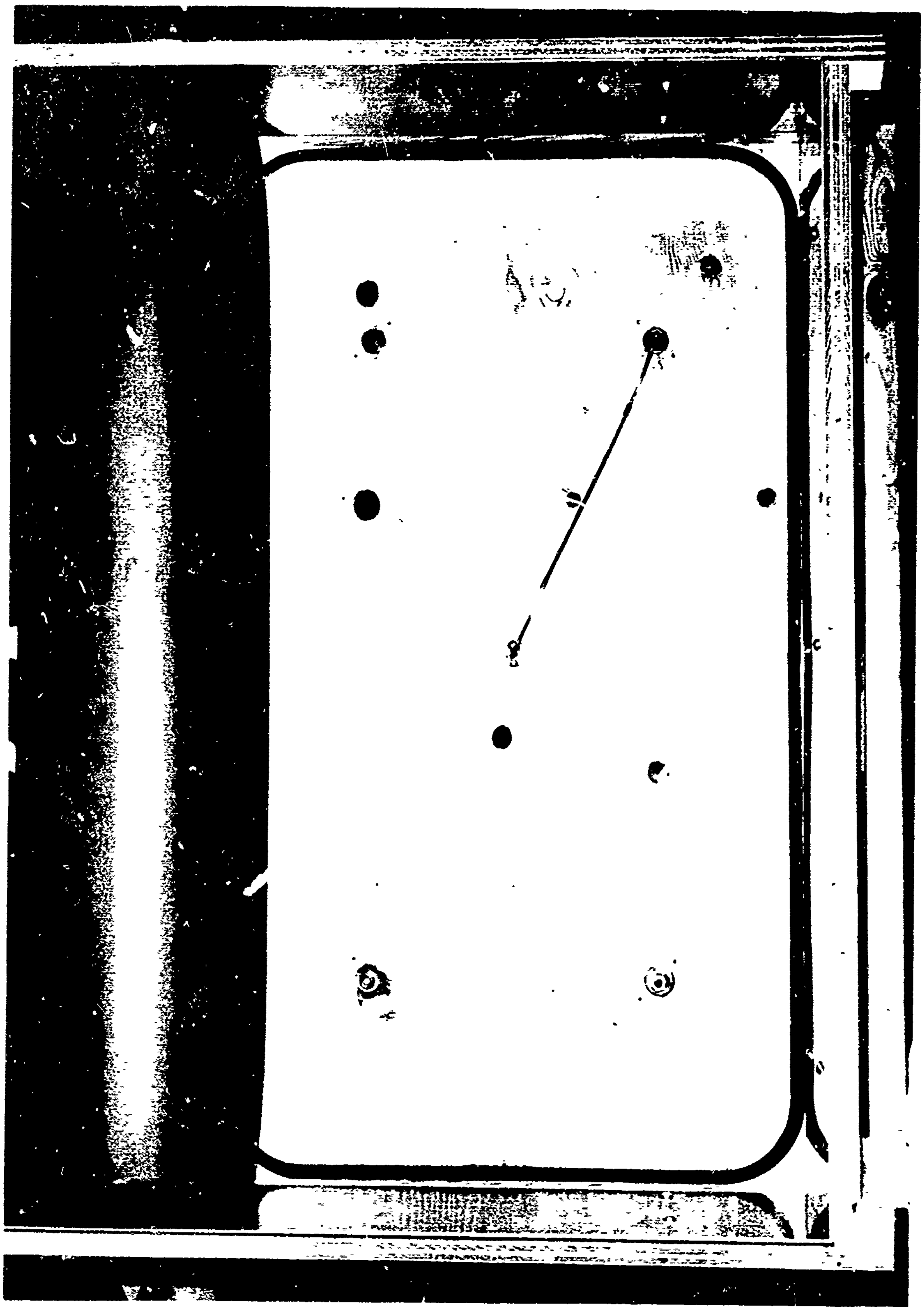


Figure 3. Underside of Skirt Model Test Box with Cylindrical Skirt Installed.

was not tested in its original form), into a tapering extended jet type as shown in Figure 4.

It was evident from previous tests that any skirt of the inflated type in which the inflated structure was continuous along the periphery, would be inherently very stiff. In order to obtain sufficient stiffness to prevent excess lateral deflection, internal pressure would be required sufficient to present a very unyielding surface to the passage of ground obstacles.

The inverted pyramidal shape with wide attachment base and with the jet orifice at the bottom appeared to offer more promise. The slightly curved walls almost meeting at the apex would form a good structure to resist lateral loads, while the large inclined angle of these walls should assist deflection over an obstacle. Internal pressure due to cushion air flow would be resisted by the closely spaced diaphragms, and would be balanced on the inside by the pressure of the air cushion.

The first model was constructed as shown in Figure 4 and tested on the model box rig. With the skirt gap set at 1/2 inch, a base pressure of 6 inches of water was the maximum that could be obtained with the available compressed air supplied to the ejector. Lateral deflections were very small and well within acceptable limits. Due to the shortness of the specimen and the fact that the ends were free, the internal pressure in the skirt produced gaps at the end plates. The ground gap increased to 1-1/2 inches due to deflection of the central section of the skirt specimen. It was very difficult to pass obstacles through the skirt specimen.

The above test indicated that the design was too stiff due to the internal diaphragms and attaching reinforcements between diaphragms and skirt walls. It was decided to eliminate most of the diaphragm material, leaving only enough at the jet exit to restrain the jet lips. This was done as shown in Figure 5.

The model shown in Figure 5 was tested in a similar manner to the previous model. Lateral deflections were within limits and the gap increased as before. It was much easier to pass obstacles through this model.

By letter from USATRECOM dated 20 October 1964, to DDP, it was agreed that the contractor could delete the requirement to conduct laboratory attrition tests on skirt materials. This allowed more effort to be extended to skirt model evaluation testing.

From November 1964 to January 1965, design work and laboratory testing of skirt models formed a continuation of the program of previous months. In addition, some time was expended in reviewing skirt concepts against existing design patents.

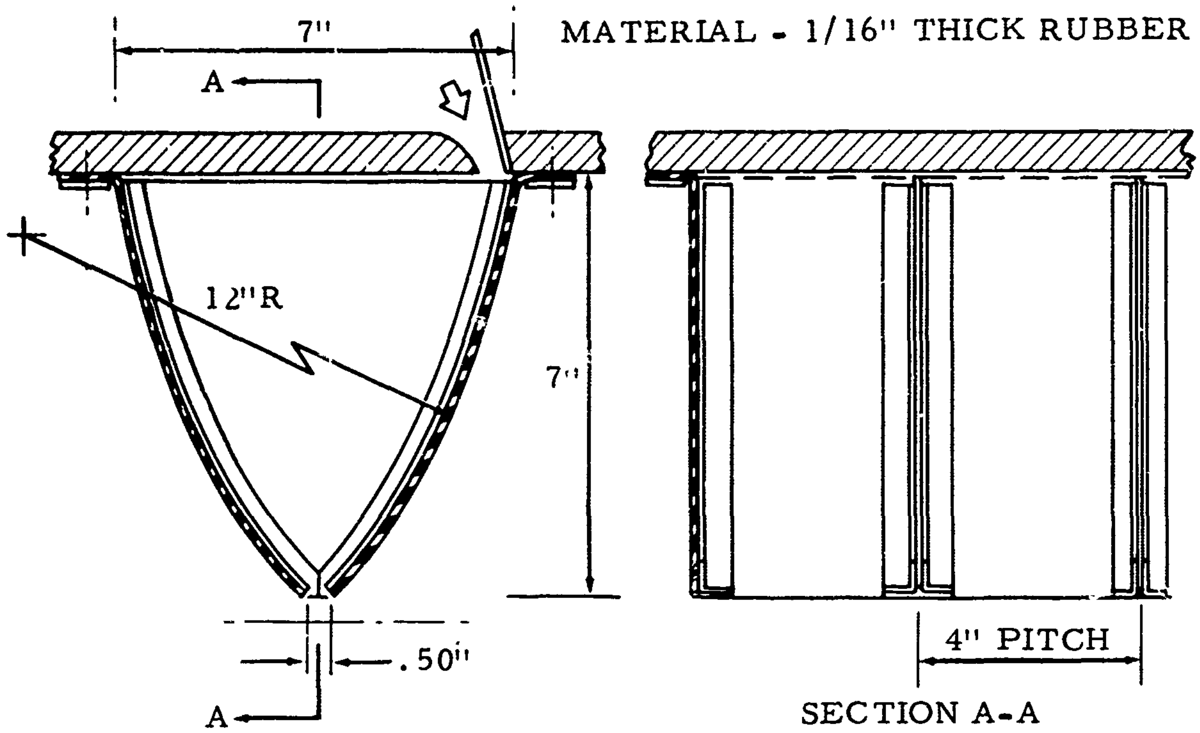


Figure 4. Details of Model Skirt No.6.

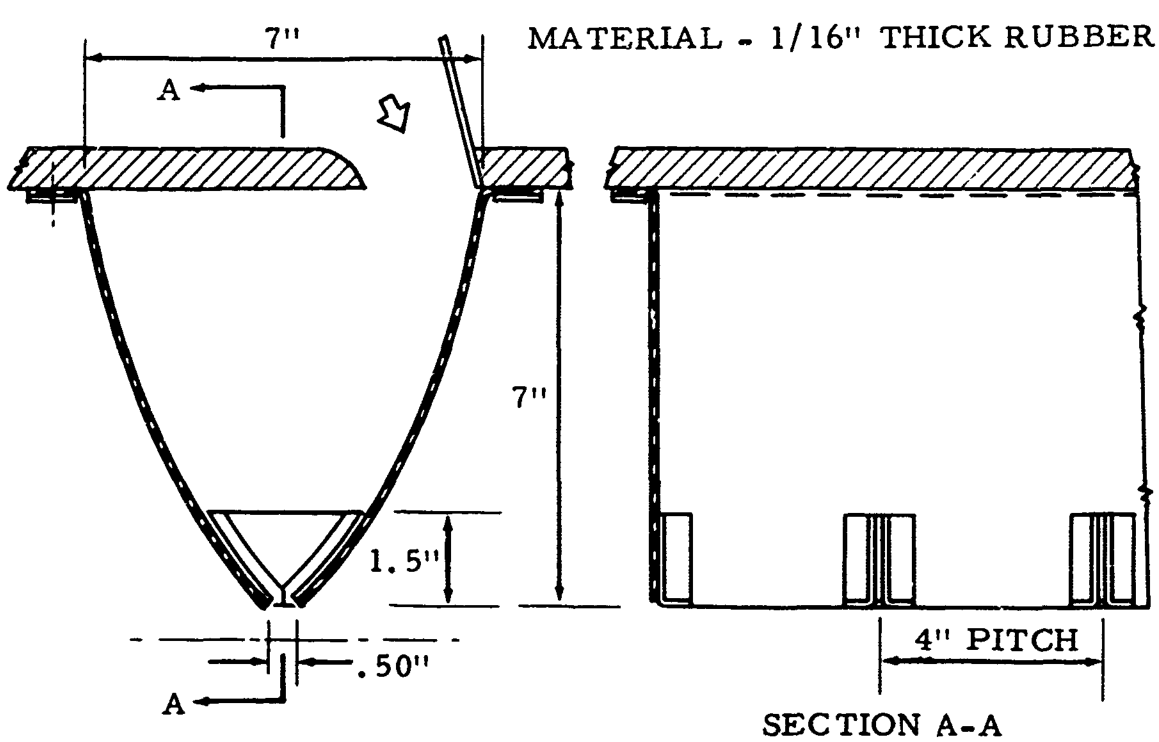


Figure 5. Details of Model Skirt No.6A.

The type of skirt investigated had the cross-section of a V with the jet opening at the bottom. The two rubber side walls were radiused and restrained under cushion air internal loading by bridges or ties of rubber connecting the sides.

Under previous testing it had been found that, although the model retained its shape reasonably well, the portion at the jet outlet deflected excessively both laterally and vertically. This was partly due to the fact that the specimen was relatively short and was not restrained at each end. A test was carried out with the ends restrained by means of plates bolted to the test frame. Under a cushion base pressure of 6.2 inches of water, the jet moved out 2 inches and the gap to base increased 1 inch. The jet outlet which was nominally 1/2 inch increased in width between the bridging to 1-1/4 inches. The jet efflux was directed horizontally along the base plane, and no Coanda effect was present as found with plenum type skirts.

It was decided to reduce the spacing of the bridging pieces connecting the walls in an effort to reduce expansion of the jet walls under air pressure. This modification was carried out using thin fiberglass cloth gussets bonded to the sides. Spacing was reduced to 2 inches from 4 inches. The end bulkheads of the test specimen were restrained as in the previous test.

Measurements were made of the changes in dimensions under cushion pressure as before. In this case, outward movement of the skirt bottom was reduced to 1-1/2 inches, the ground clearance increased from 11/16 inch to 2 inches, and jet opening increased between bridging from 1/2 inch to 3/4 inch.

A pyramidal obstruction was attached to the plywood base, the latter representing the ground, and this was passed back and forth through the skirt while the ground cushion was in effect. The force required to move this obstruction through the skirt was a small fraction of that required under similar circumstances when tried with the inflated type models.

As a result of the tests on skirt models carried out in previous months, a decision was made to submit a skirt design based on the most promising configurations tested, for approval as per contract.

A drawing was prepared, No.400C01012, Skirt Type 6D, (Figures 6 and 7) and submitted. This design differed from the test model in that the cloth ribs connecting the sides were replaced by small round metal ribs, bolted at each side.

Approval of the design was received in March 1965, and action was taken to implement the manufacture of the skirt.

The shops proceeded with fitment of the front and rear skirts in June 1965. The front skirt was received from the sub-contractor and was assembled to the vehicle. Some difficulty was experienced at the corners, where a small tuck had to be incorporated. The rear skirt, received in an unassembled condition so that a better fit could be obtained by fitting and bonding on assembly to the cushion, was incorporated onto the vehicle base structure (Figure 8).

TEST RESULTS

Hard Surface Testing with Modified Splitter, without Skirt

Tests performed at a cushion height of 1.5 inches showed a gain of 700 pounds of lift over the lift of previous tests and indicated lower losses with the modified splitter. Previous tests had shown flow-breakaway at the splitter which caused a loss of pressure to the front jets. Traverses with the new configuration are compared in Figure 9 with that obtained with the original splitter, shown by the solid line. As can be seen from Figure 9, the curves of total pressure are now smooth but do indicate a deficiency of pressure rise at the hub of the fan. Changes to the jet gates to alter the flow ratio between the front and rear sections seem to influence the fan operation. With the front flow reduced to 10%, the deficiency in the hub pressure and velocity is greater than in the other two cases where 61% and 90% of the flow was directed to the front jets. The variation of static pressure from inner wall to outer wall shown in Figure 9 is much less than that measured with the original splitter and casts doubt on the accuracy of the inner wall pressure measured previously.

As a result of the elimination of the pressure loss associated with flow-breakaway from the splitter, the front duct loss was reduced from its previous value of 11% of the fan pressure rise to a new mean value of 7.4%. Since the flow to the rear ducts was not affected by the flow-breakaway from the splitter in previous tests, no noticeable change occurred in the present tests, the pressure loss remaining at about 17% of the fan pressure rise for normal flow division.

Figure 10 shows the results of the analysis of duct losses. The front duct shows scatter about a mean value of 7.4% of the fan pressure rise. Some of this scatter is no doubt associated with changes of the fan outlet pressure profile near the hub (Figure 9). This would vary the total initial energy in the flow to the front duct.

For the rear duct a correlation between loss and estimated flow is evident, the variation being roughly proportional to the second power of the flow.

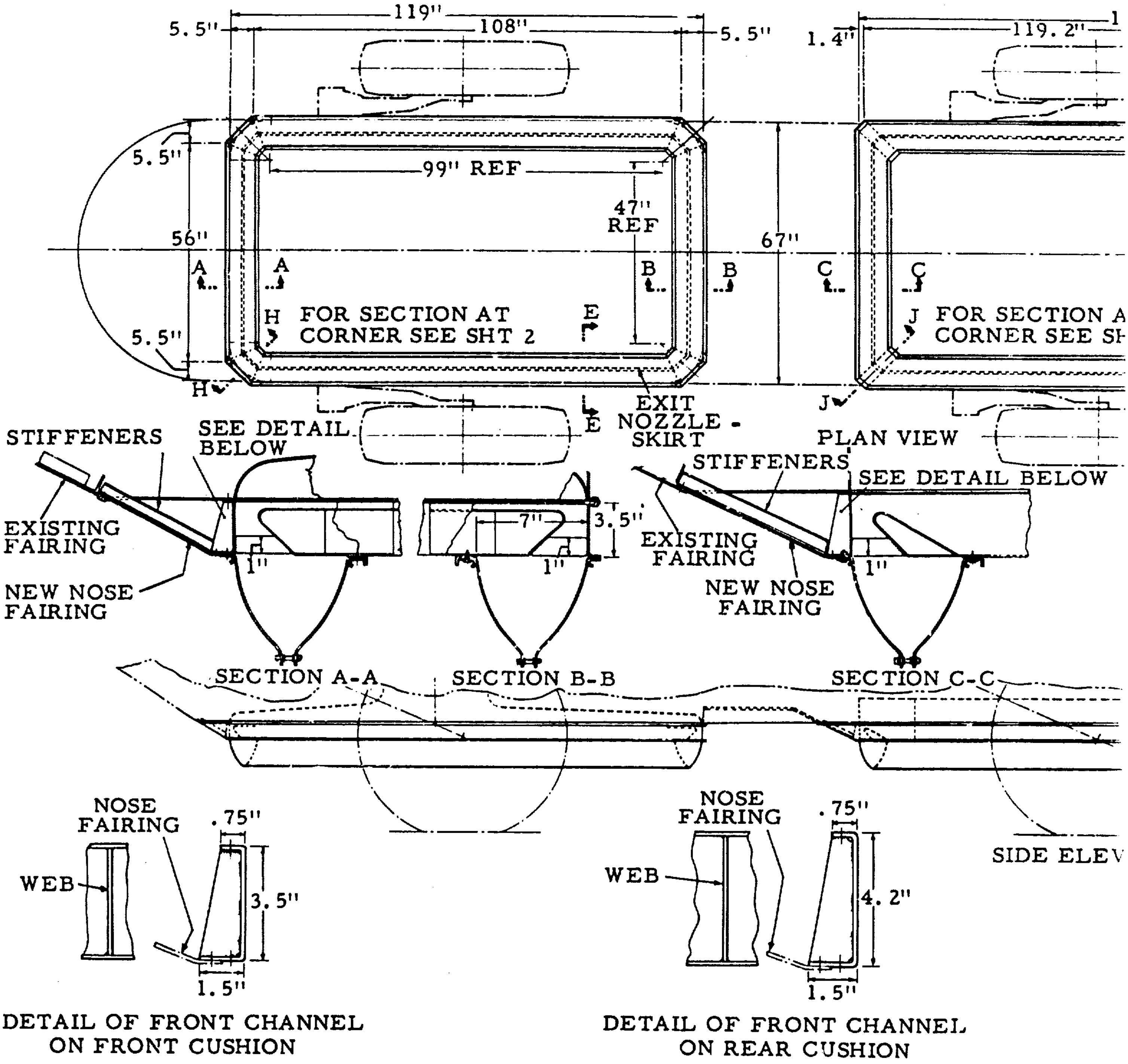


Figure 6. Skirt Type 6D and A

A

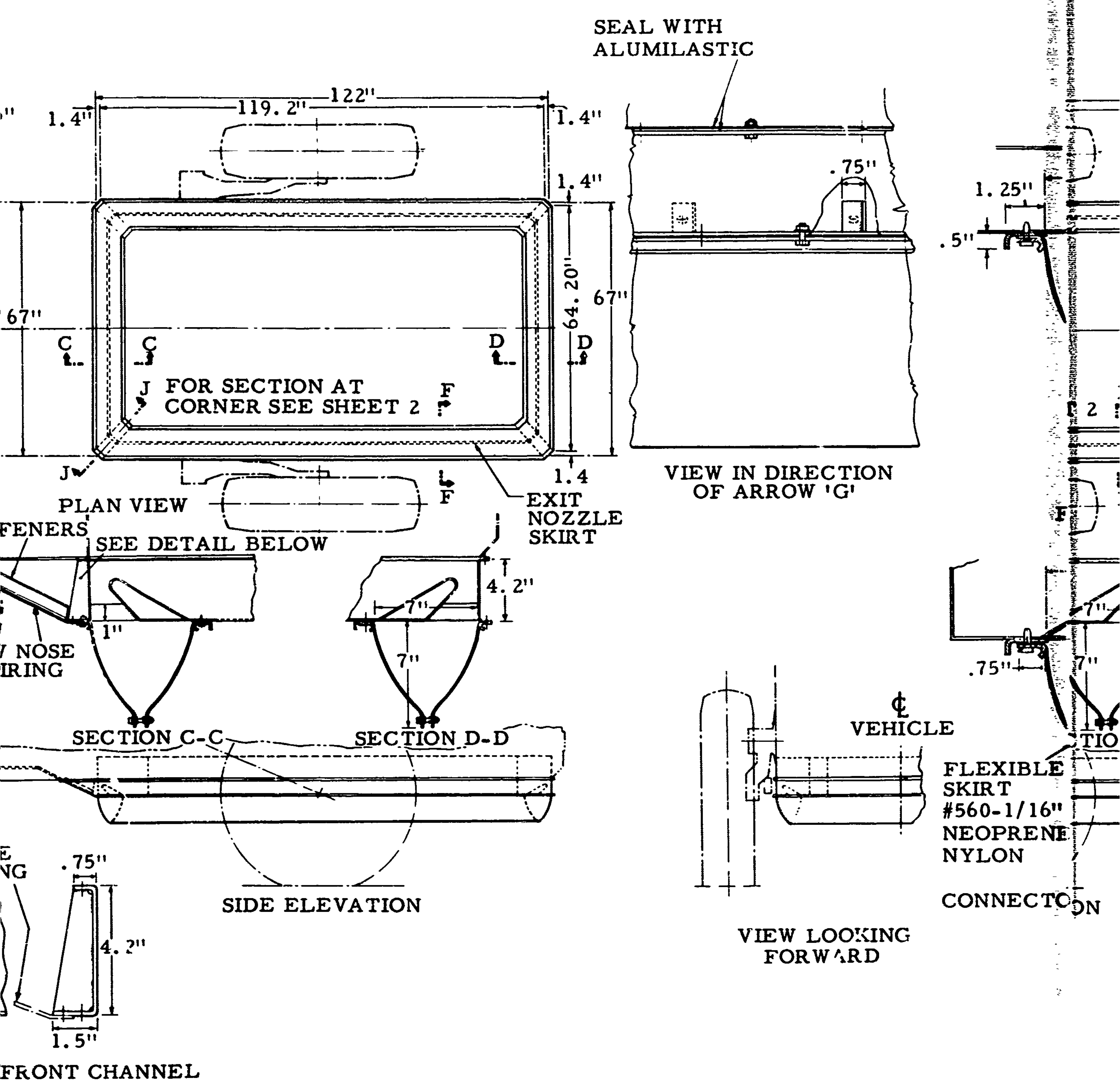
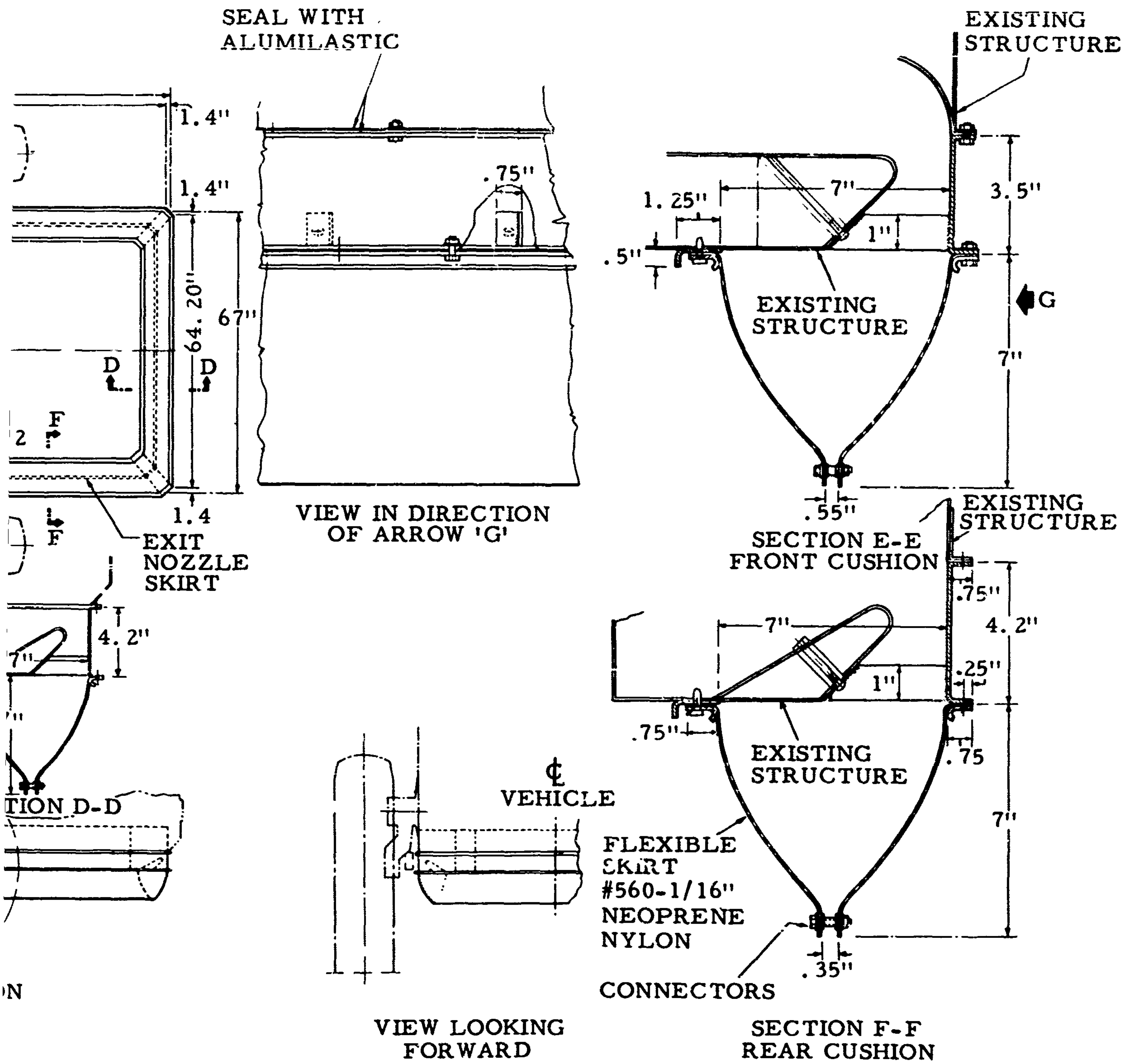


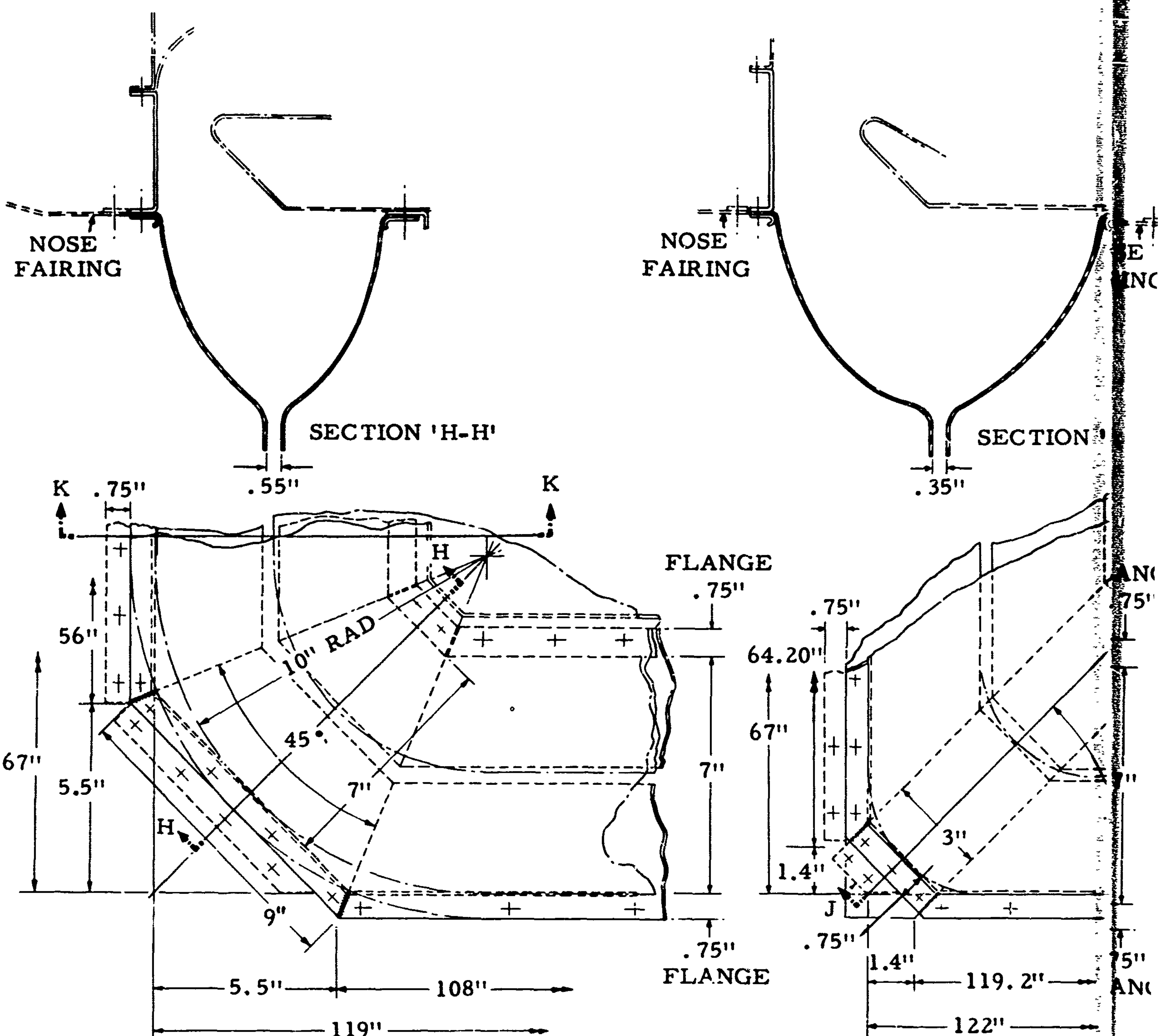
Figure 6. Skirt Type 6D and Attachment to Vehicle (Sheet 1).

B



ment to Vehicle (Sheet 1).

C

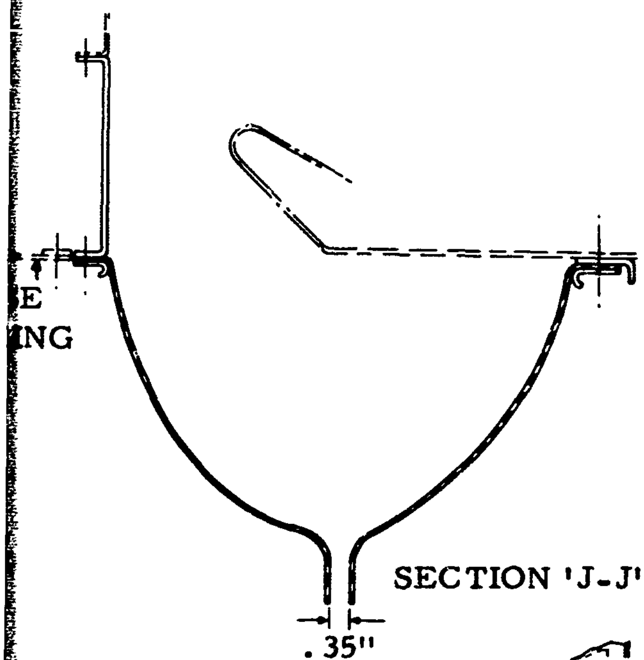


L.H. FRONT CORNER - FRONT CUSHION
TYPICAL FOR FRONT CUSHION

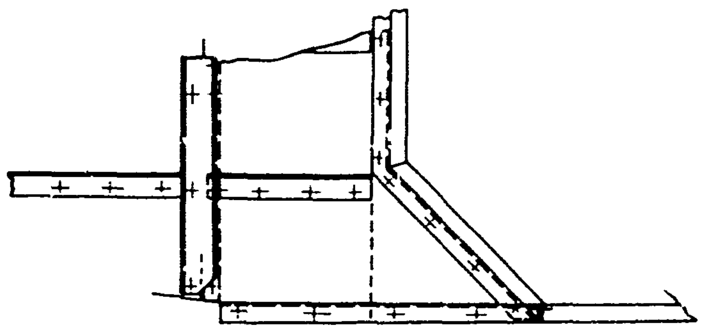
L.H. FRONT CORNER - R
TYPICAL FOR REAR

Figure 7. Skirt Type ɩJ and Attachment to Vehicle (Sh 6D

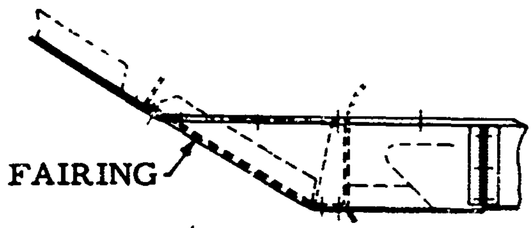
A



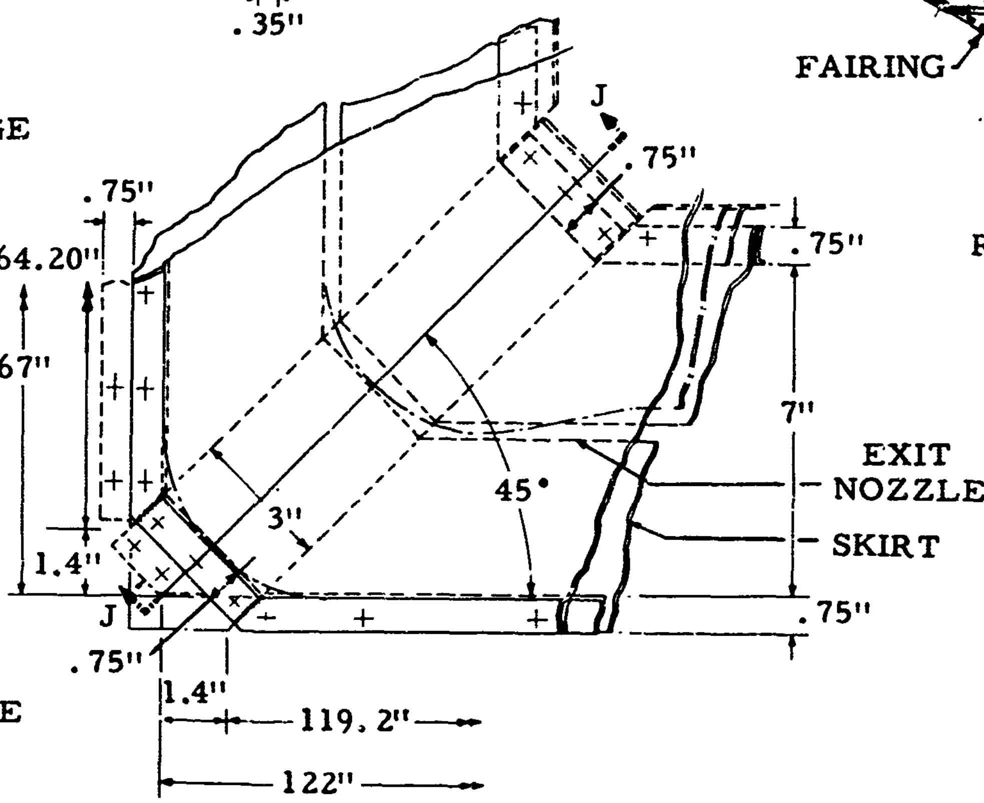
SECTION 'J-J'



PLAN VIEW



SECTION K-K
FRONT CUSHION -
REAR CUSHION SIMILAR



L. H. FRONT CORNER - REAR CUSHION
TYPICAL FOR REAR CUSHION

6D and Attachment to Vehicle (Sheet 2).

B

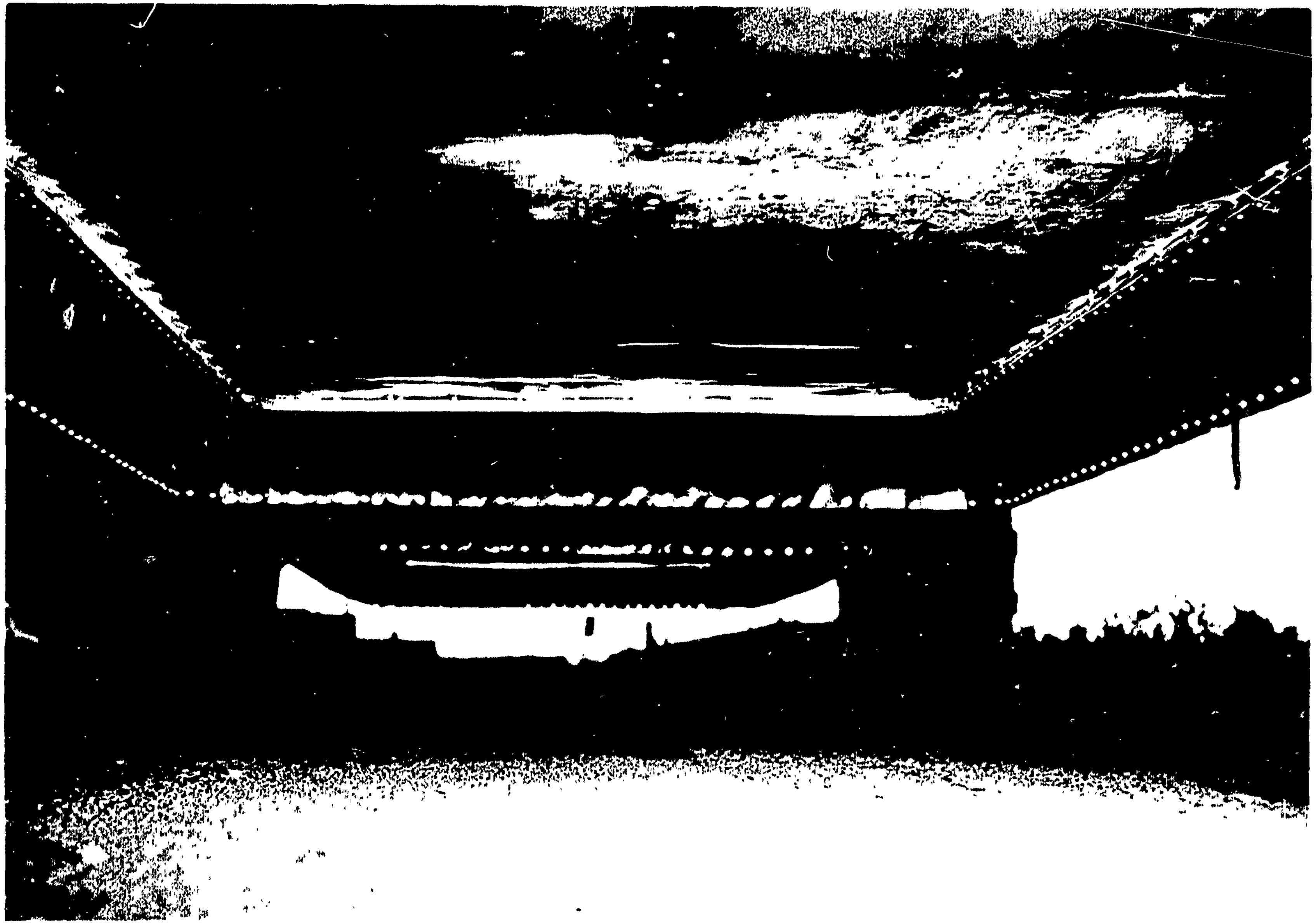


Figure 8. Underside of Test Vehicle with Skirt Installed.

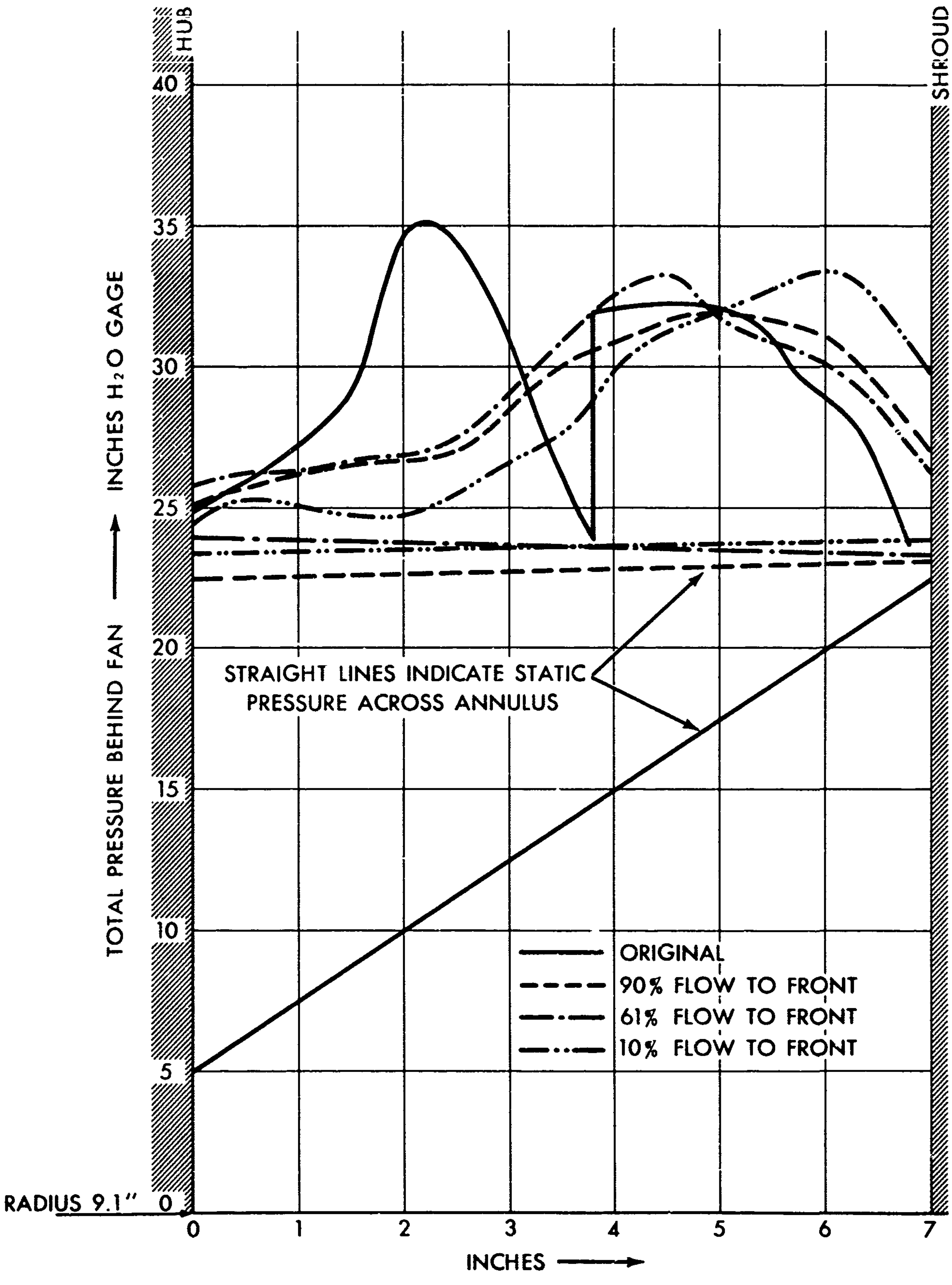


Figure 9. Comparison of Velocity Distribution - Original vs. Modified Splitter.

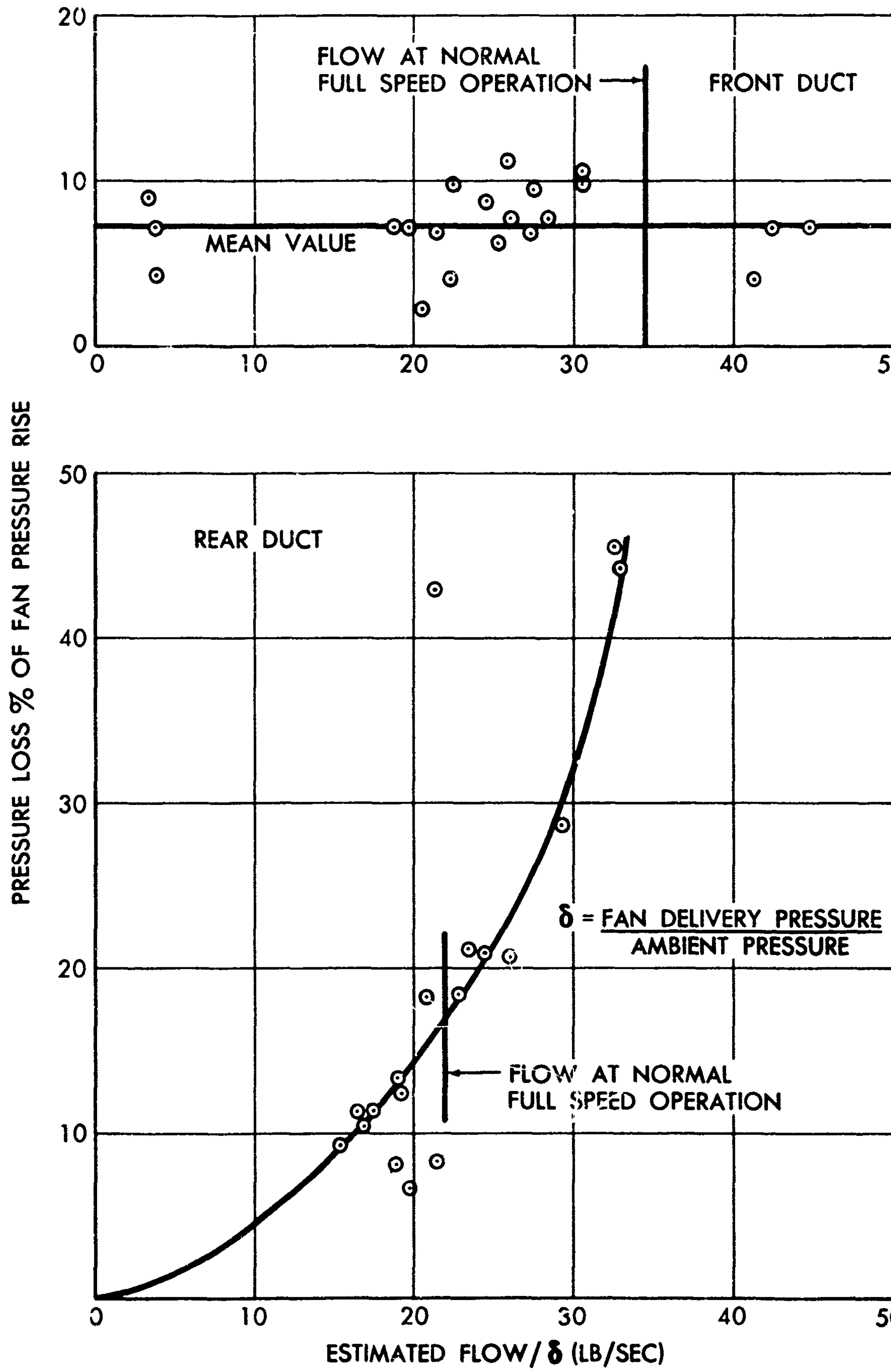


Figure 10. Duct Losses vs. Flow

Tests were performed over level concrete using various combinations of jet gates to assess the effect on lift of varying mass flow between front and rear cushions. Figure 11 shows the values of lift calculated from base pressure when the flow to the front was varied from an estimated value of 10% of the total flow to 90%. The rear lift curve indicates that the estimated value of 90% flow to the front appears to be excessive and the dotted curve is more to be expected. It was found quite feasible to vary the lift between front and rear cushions, but any departure from optimum jet widths was accompanied by a loss in total lift (Figures 11 and 12).

From these tests it was decided that the optimum configuration was that with a flow split of 61% to the front and 39% to the rear. This gave the same ratio of front to rear lift as the original configuration (Figure 12) and, as this had proved successful in the early field trials, it was decided to retain this ratio.

Waterborne Testing

On completion of hard surface testing of splitter modifications, the test vehicle was prepared for water tests to be conducted at Dinner Lake, Parry Sound Proving Grounds.

The side jet gates and thrust vanes were removed and the 45° thrust vanes were installed, together with optimum jet gates.

The hydrostatic drive was assembled to the vehicle and adjustments made to relief valves, filters and other related components to ensure correct operation. The vehicle was transported by low-bed trailer to Dinner Lake on 25 August 1964.

First runs of the test schedule were undertaken with rearward thrust jet vanes and optimum jet gates to determine water speed and general handling, for various depths of wheel immersion and a range of wheel and vehicle speeds. The vehicle was ballasted to its gross weight for all tests. Recording instrumentation was installed for measurement of wheel speeds, motor pressures, pump r.p.m. and static pressures. Vehicle speed was measured by fixing one end of the cord from a "fishing reel" transducer, the reel speed signal being fed into a recorder as the vehicle moved off. Drawbar pull was measured by anchoring one end of a cable to shore and attaching the other end to a dynamometer fixed to the stern of the vehicle. Signals were fed into the recording gear from the dynamometer.

Many runs were necessary, as no directional control is fitted to the vehicle, which yawed considerably and was sensitive to wind forces.

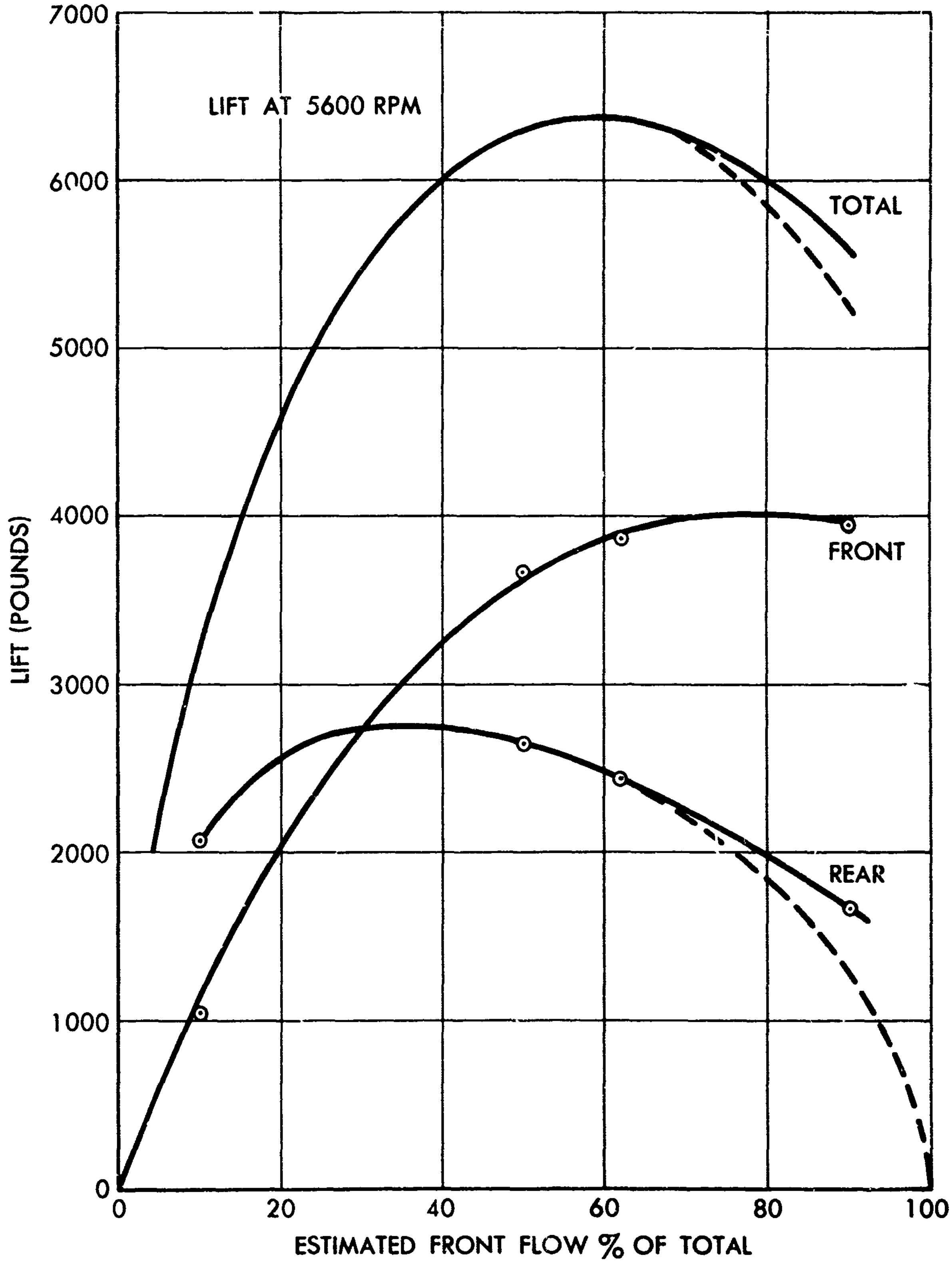


Figure 11. Variation of Lift with Flow Division.

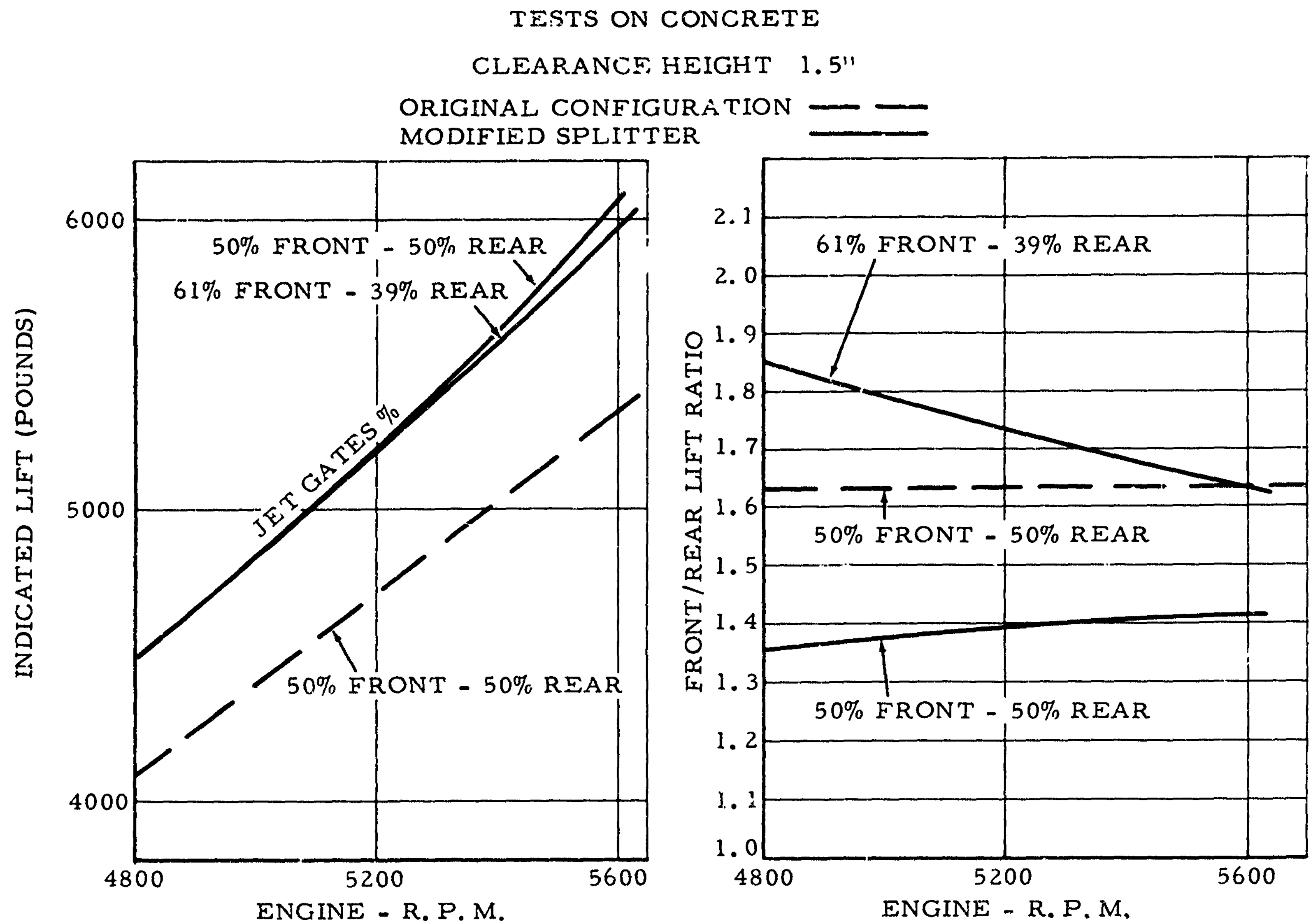


Figure 12. Lift vs. Engine r.p.m. - Hard Surface Testing with Original and Modified Splitter.

Runs were then made with the air cushion fan operating in conjunction with the wheels. Speeds and drawbar pulls were measured.

The above program was repeated with vertical jet vanes from 1 September to 4 September 1964. Twenty runs with recording apparatus activated were made. Additional runs were made to check testing techniques. Due to excessive yaw and directional instability aggravated by wind conditions, readings taken during runs with the air cushion fan operating yielded unusable data.

Some photographic coverage of these tests was made (see Figures 13 and 14).

Recorded results with fan off are shown in graphical form on Figures 15, 16, and 17.

It is apparent that wheel propulsion is inefficient. Present tires used as paddle wheels have excessive slip and will not absorb sufficient power for propulsion. In view of this deficiency, maneuverability is also poor, since a reasonable speed is required to maneuver the vehicle. Lateral stability is sensitive to the jet cushion. At part throttle, air is ejected from one side of the cushions and tends to roll the vehicle and propel it sideways. With the tires acting as paddle wheels and with the air cushion on, a better speed was achieved, but with less maneuverability, due to uncontrolled forces of the jets.

Hard Surface Testing with Skirt Installed

From 21 to 22 July 1965, hard surface tests were carried out with wheels removed to determine clearance between skirt and ground for lift-off (Figures 18 and 19). Lift-off was achieved when the clearance, with air pressure in the skirt, was 1/8 inch at the corners and 3/4 inch at the mid-point of each side on both the front and rear skirts, with engine speed at 5500 r.p.m.

The maximum base pressures at 5500 r.p.m. recorded during the hard surface tests were 80.4 pounds per square foot on the front air cushion and 46.25 pounds per square foot on the rear air cushion, for the above conditions. Because of deflection of the skirt under air pressure, it was necessary to set the vehicle with the skirt riding on the ground, an interference of 1.25 inches being necessary to achieve a reasonable air gap under pressure.

During the period 18 to 20 August, additional hard surface tests were carried out to determine the effect on base pressure of installing wider

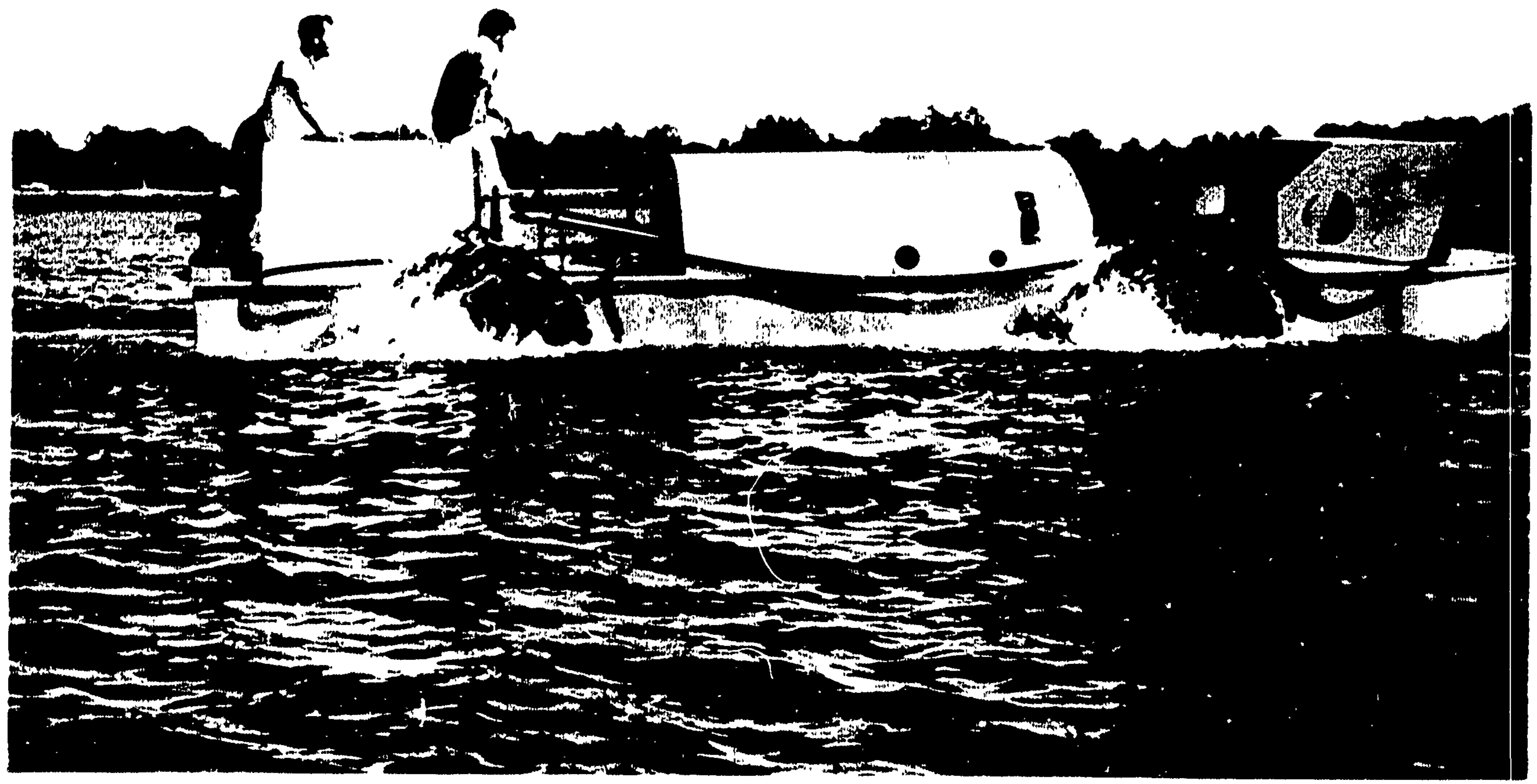


Figure 13. Side View of Test Vehicle with Fan Off During Waterborne Tests.

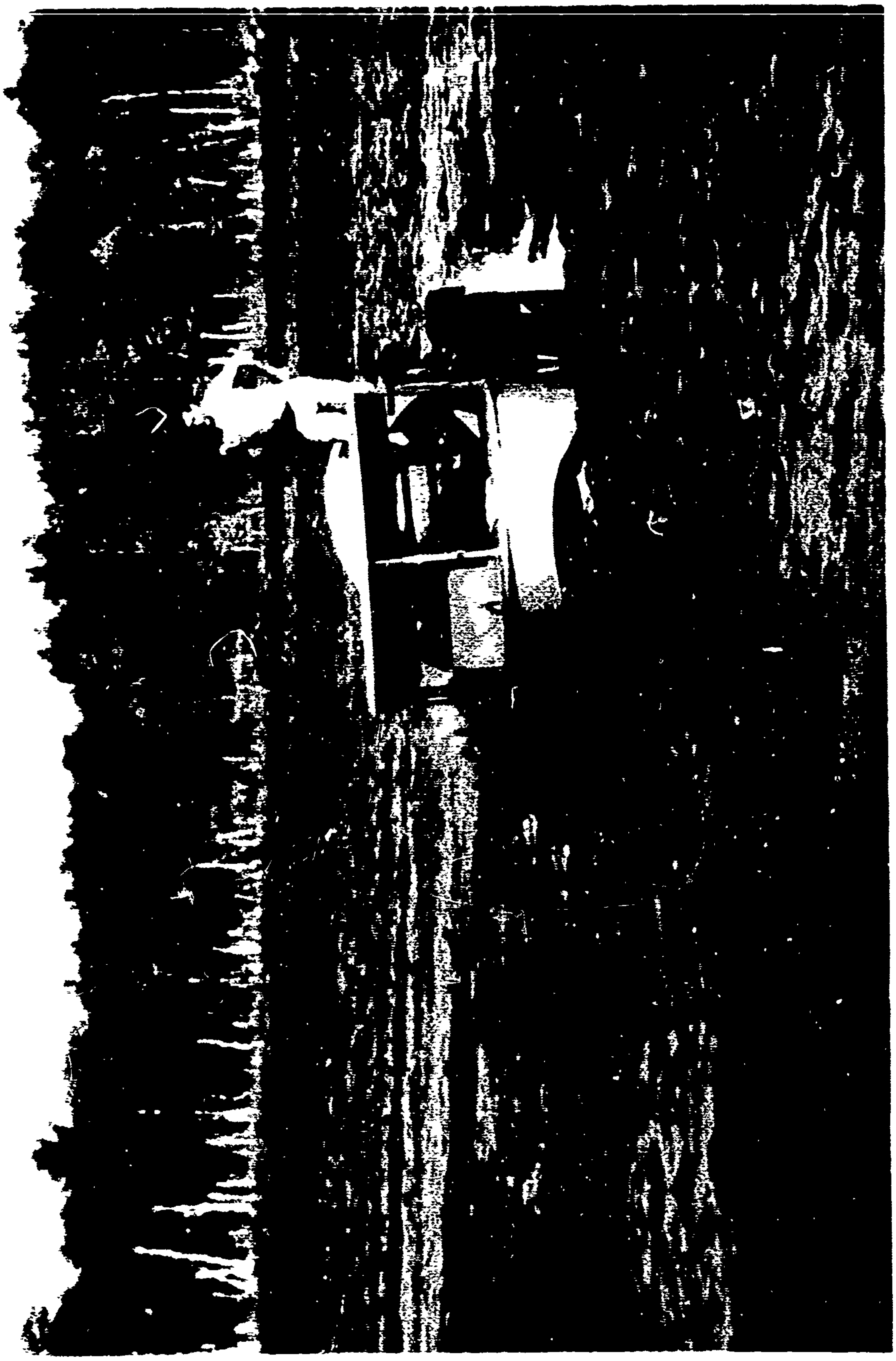


Figure 14. Front View of Test Vehicle with Fan Off During Waterborne Tests.

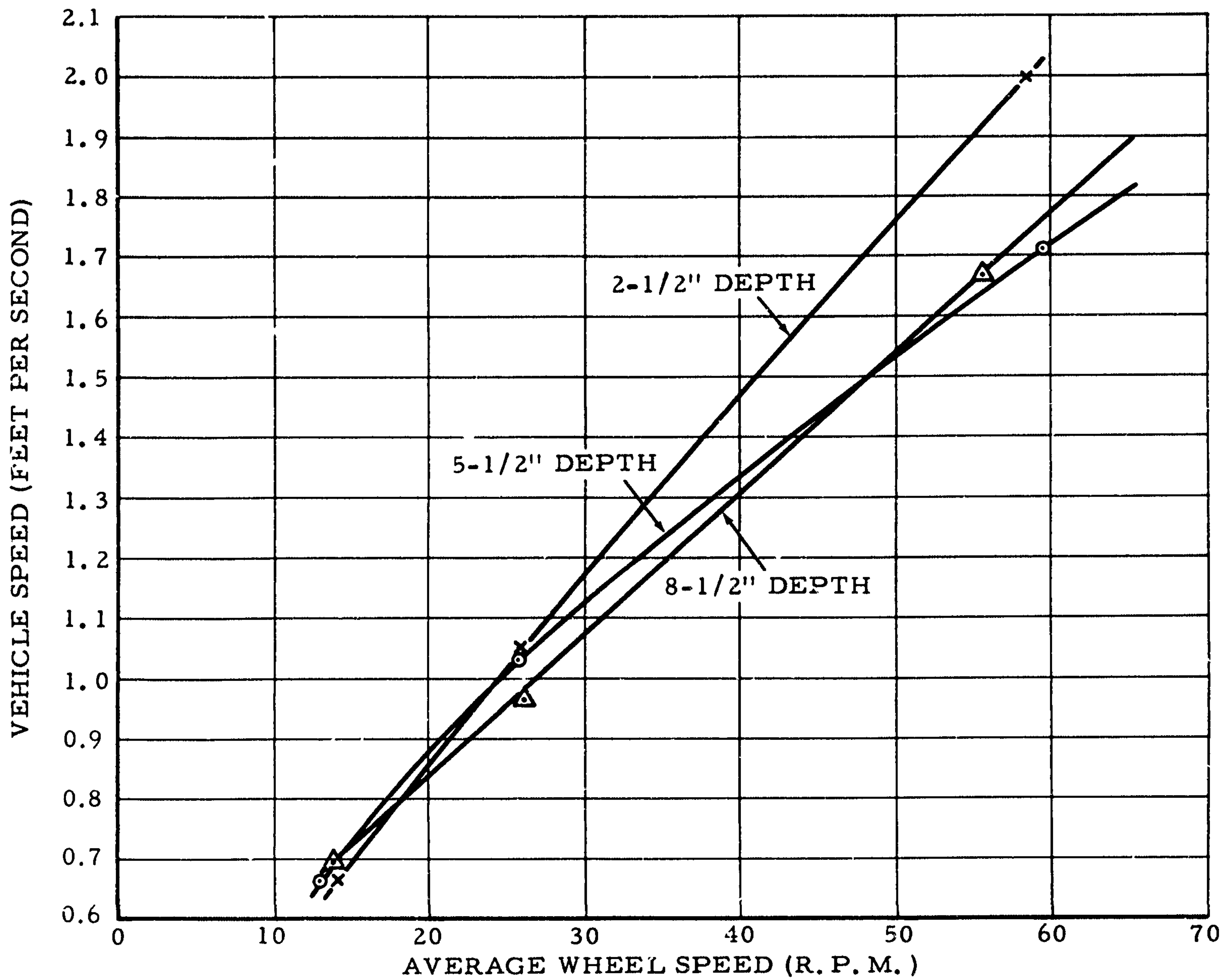


Figure 15. Vehicle Speed vs. Average Wheel Speed - Waterborne Tests with Fan Off.

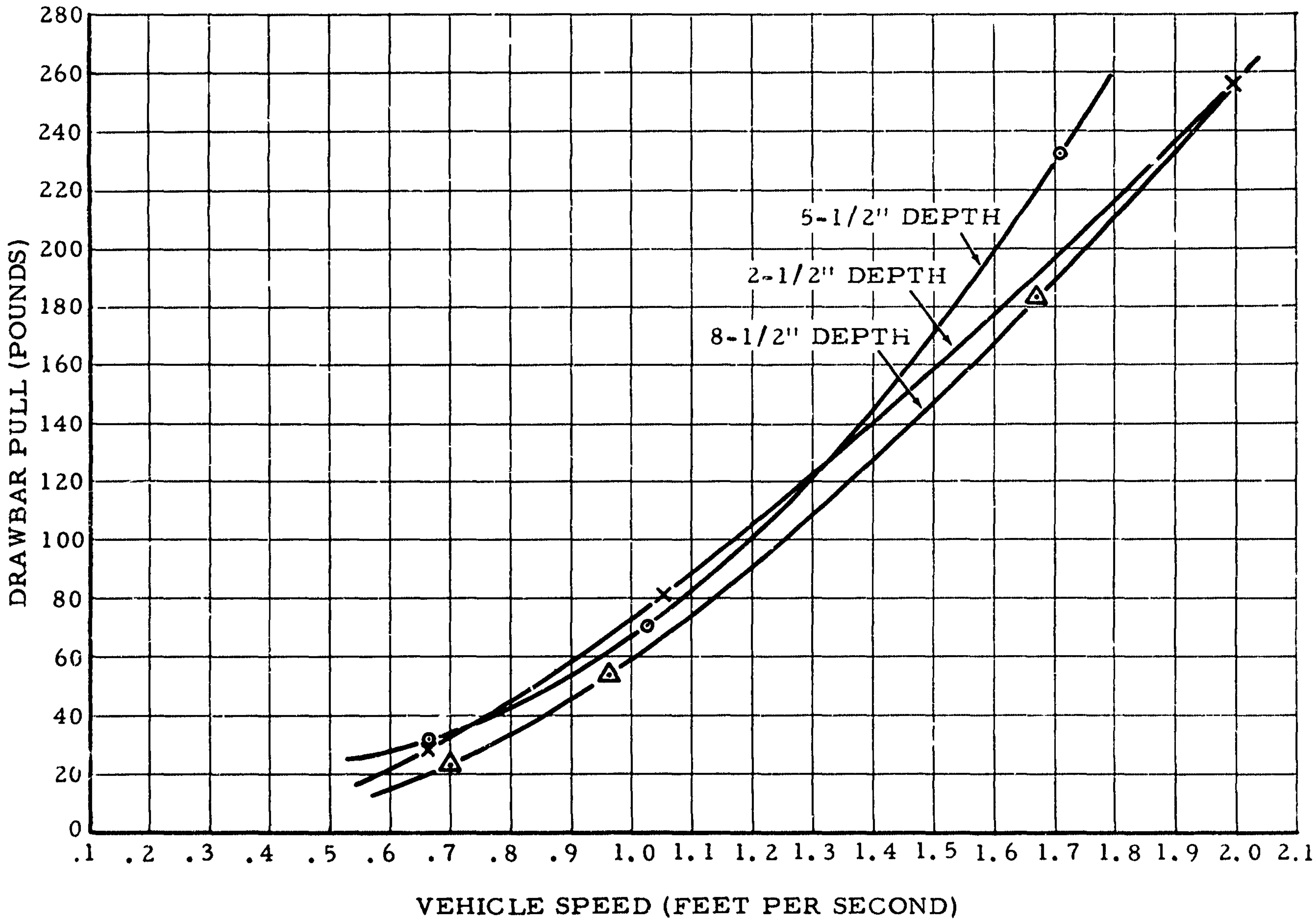


Figure 16. Drawbar Pull vs. Vehicle Speed - Waterborne Tests with Fan Off.

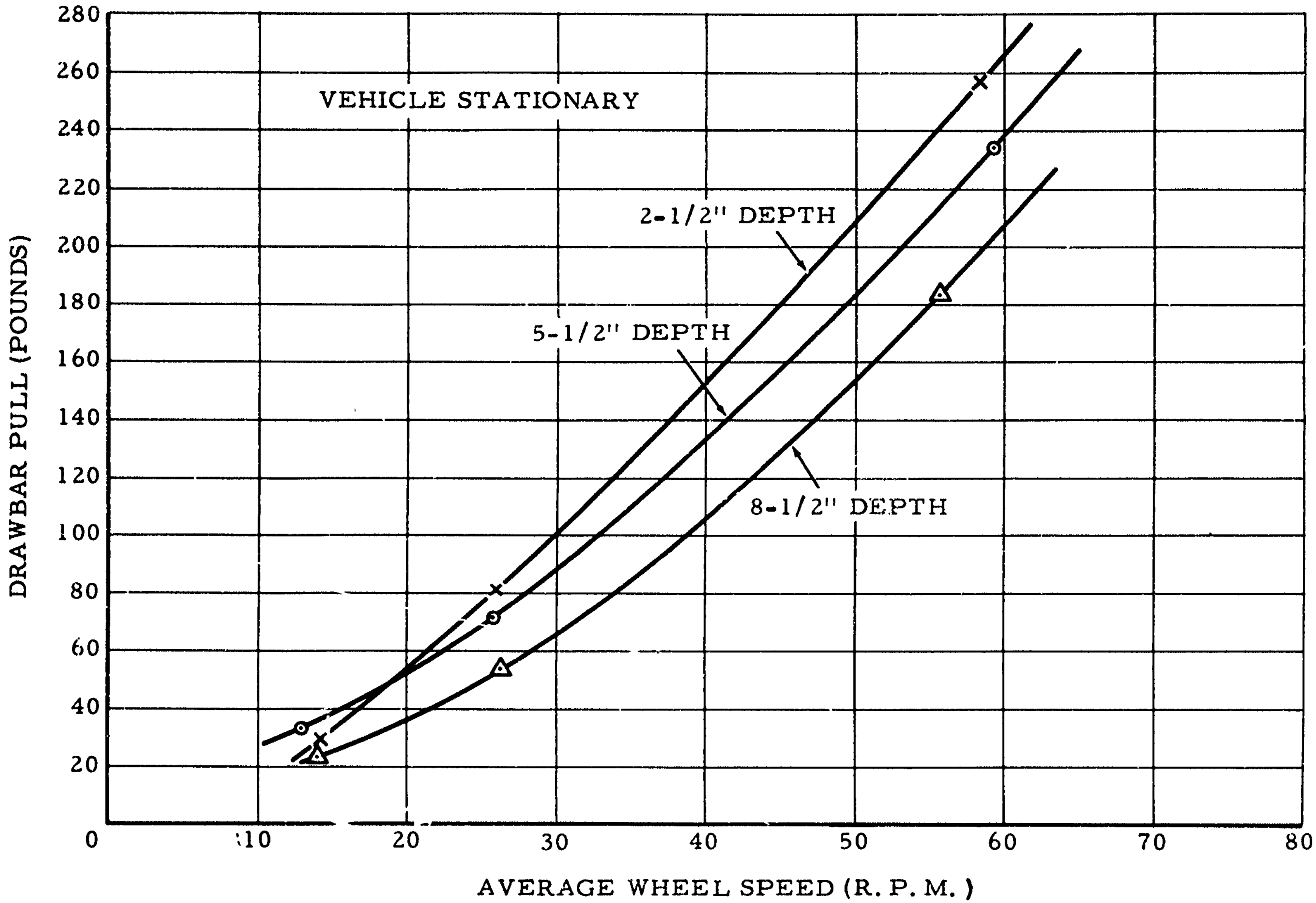


Figure 17. Drawbar Pull vs. Average Wheel Speed Waterborne Tests with Fan Off.

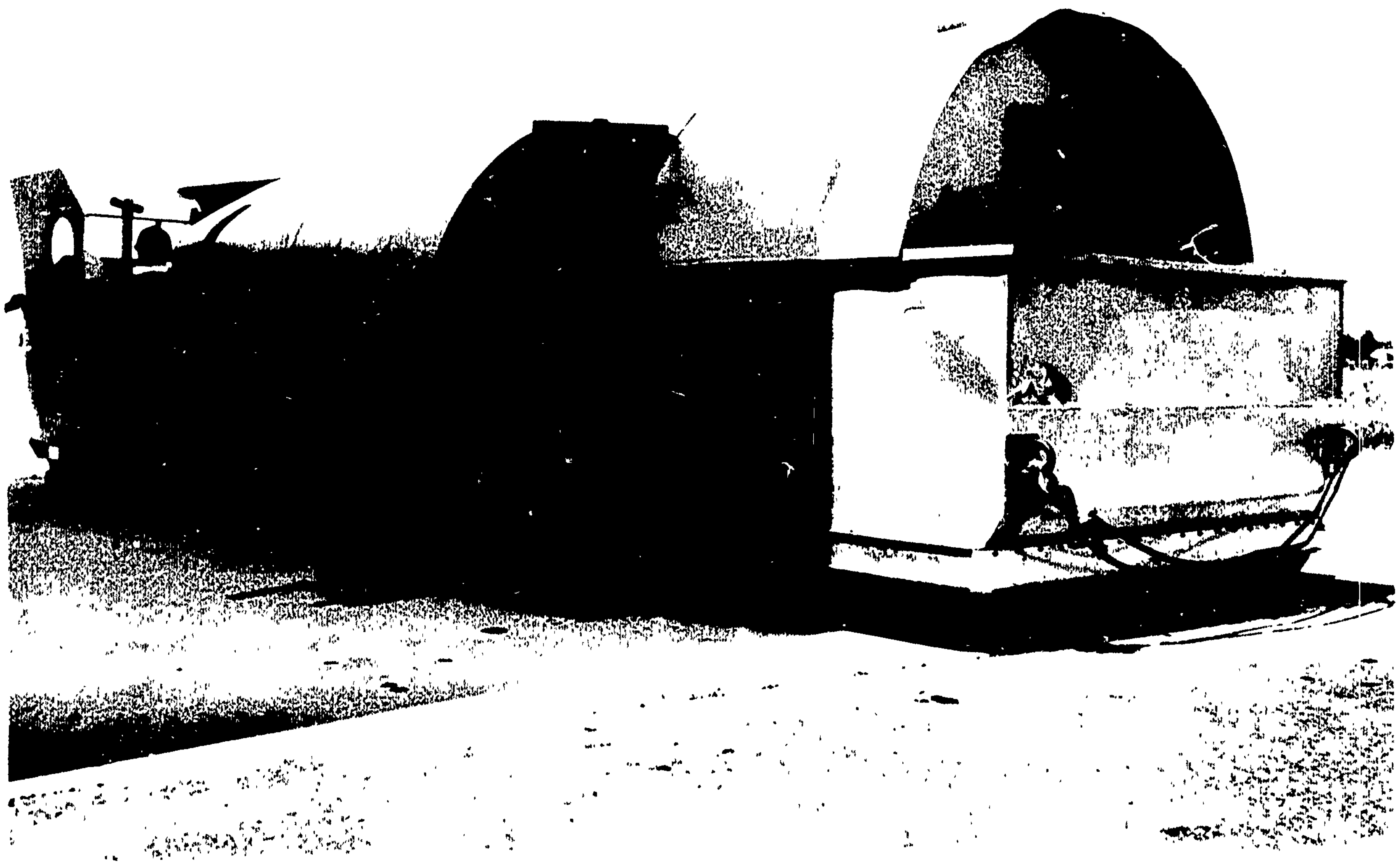


Figure 18. Test Vehicle with Wheels Removed and Skirt Installed.

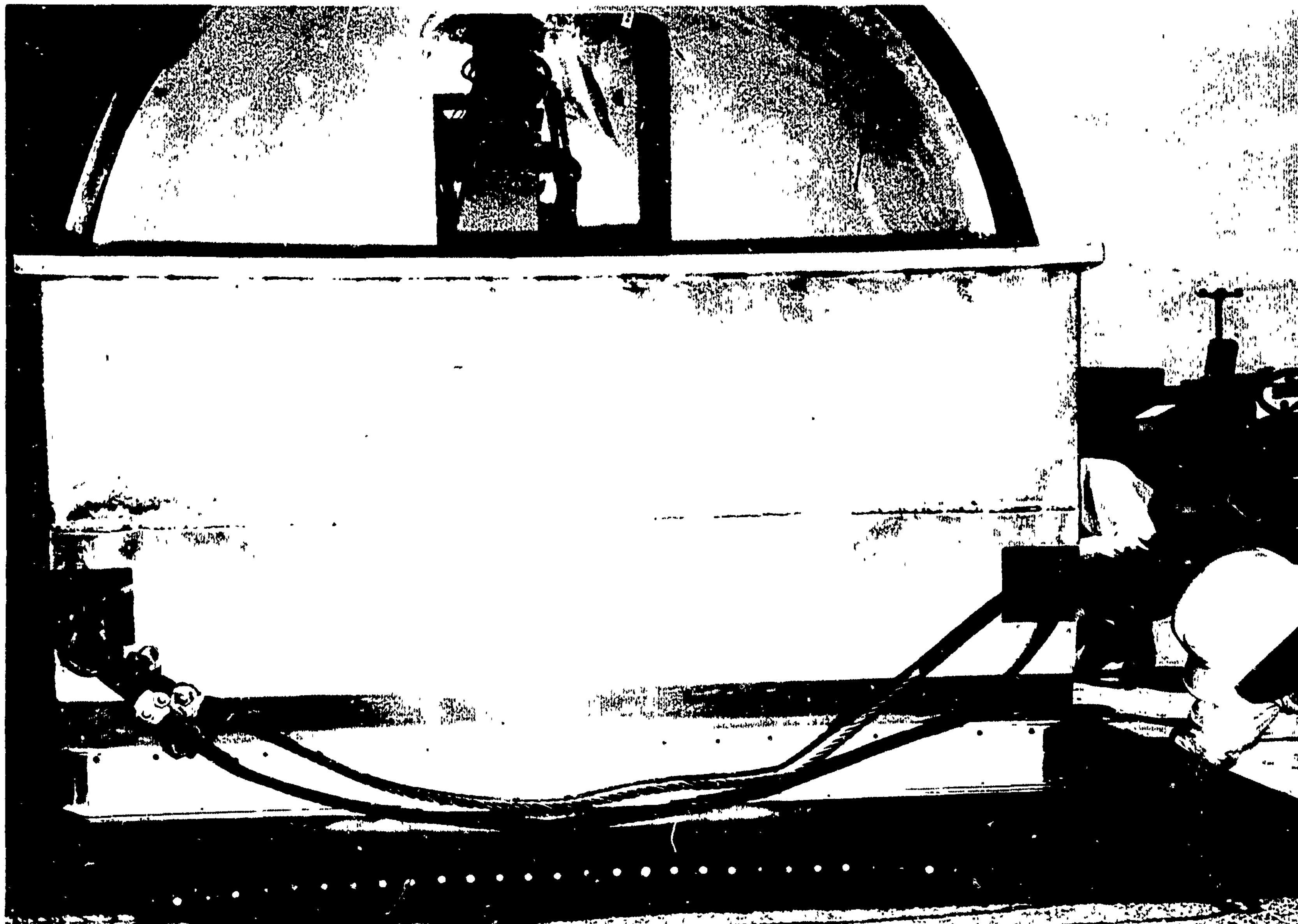


Figure 19. Rear of Test Vehicle with Wheels Removed and Skirt Installed.

spacers in each corner of the rear skirt and also to determine by Pitot probe traverse the uniformity of the air flow around the periphery of the front and rear skirts. The base pressures obtained were essentially the same as those recorded during the tests carried out in July (Table I). The results of the air flow survey were not conclusive, mainly because vibration of the skirt influenced the measuring probe.

TABLE I

HARD SURFACE TEST RESULTS

Date	Engine Speed (r.p.m.)	Static Ground Interference (Inches)	Fan Total Pressure (P.S.F.)	Base Pressure (P.S.F.)	
				Rear	Front
Jul 22	5500	1.25	109.0	48.0	80.4
Jul 27	5600	1.25	123.0	44.8	85.0
Aug 18	6000	1.25	107.5	46.2	85.2

Clay Bed Testing with Skirt Installed

On 26 and 27 July 1965, the west clay bed was reactivated for these tests, to a consistency when measured with a cone penetrometer of 10 average at a depth of 6 inches and 15 average at a depth of 12 inches (Figures 20, 21, and 22).

During the period 28 to 30 July, several runs were attempted through the clay bed, the skirt ground clearance being varied for each run. It was noted that after the vehicle had completely entered the bed it would settle fairly rapidly and stop. At full engine power the vehicle would attempt to rise but there was insufficient traction to overcome the drag and excess buildup of wet clay in front of the vehicle.

It was observed that, as the front wheels entered the clay bed, the nose of the vehicle dropped and plowed up a wall of wet clay mixture as the vehicle progressed forward. This nose-down attitude of the vehicle also caused excessive loss of the rear air cushion. Wheel rut depths were measured up to 18 inches, and the power delivered by the hydraulic motors was insufficient to turn the wheels at this depth.

Number Above Line is Reading at Depth of 6 Inches
Number Below Line is Reading at Depth of 12 Inches

N

FEET	12	24	36	48	60	72	84
21	10 / 15	10 / 10	7 / 12	5 / 15	5 / 20	20 / 25	15 / 25
18	10 / 20	15 / 15	12 / 30	10 / 20	7 / 12	10 / 25	10 / 20
15	5 / 5	10 / 10	5 / 12	5 / 5	5 / 5	5 / 12	5 / 10
12	5 / 30	5 / 22	5 / 5	5 / 10	15 / 20	10 / 15	10 / 25
9	5 / 30	10 / 15	12 / 25	10 / 20	12 / 20	15 / 25	10 / 25
6	5 / 20	5 / 20	10 / 20	5 / 12	5 / 12	7 / 15	10 / 20
3	5 / 30	5 / 15	5 / 15	10 / 25	10 / 12	15 / 40	15 / 30

Figure 20. Gemini Clay Bed Tests -
Cone Penetrometer Readings July 28, 1965.

Number Above Line is Reading at Depth of 6 Inches
Number Below Line is Reading at Depth of 12 Inches

N

Feet	Depth	12	24	36	48	60	72	84
21	above	10	20	10				
21	below	15	25	10				
18	above	10	12	10		12	10	
18	below	35	25	40		18	20	
15	above	5	5	5		20		10
15	below	5	10	15		10		20
12	above	5	7	10	10	20	10	15
12	below	10	15	20	15	20	10	30
9	above	10	7	5	15	20		
9	below	20	15	15	30	20		
6	above	10	10	10	10	18	15	10
6	below	10	30	15	15	15	15	15
3								

FEET

Figure 21. Gemini Clay Bed Tests -
Cone Penetrometer Readings July 29, 1965.

Number Above Line is Reading at Depth of 6 Inches
Number Below Line is Reading at Depth of 12 Inches

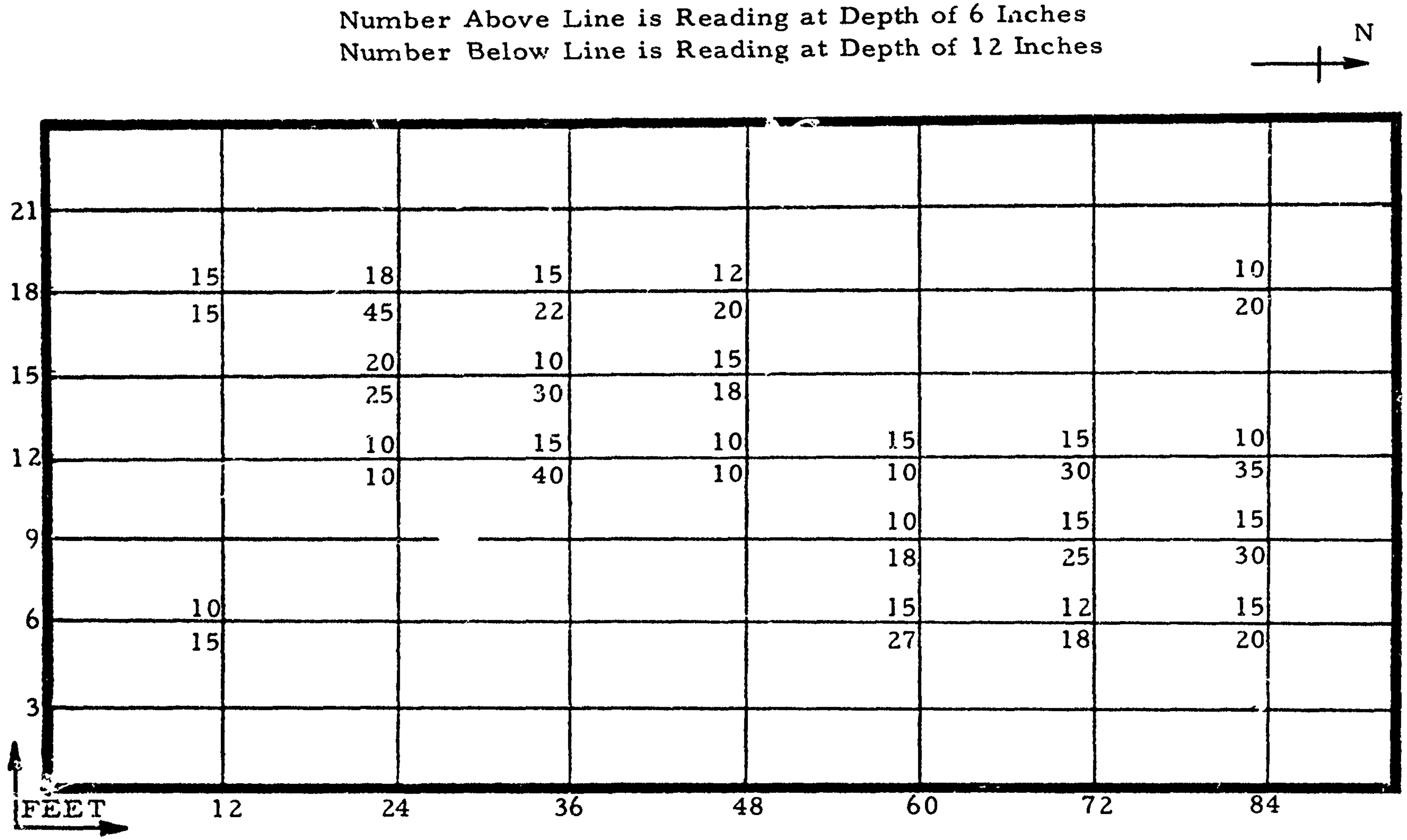


Figure 22. Gemini Clay Bed Tests -
Cone Penetrometer Readings July 30, 1965.

The tire treads also loaded up with clay during the runs, and on some occasions considerable wheel spinning was encountered. Wider spacers were installed at each of the four corners of the rear skirt, but no improvement in pressure of the rear air cushion was obtained. It was observed that the skirt was dragging, particularly at the corners which deflected less under air pressure than the side walls.

A comparison of the cone penetrometer readings of the west clay bed as prepared in October 1963 and as prepared for the tests currently carried out, show the former to be 37 average at a depth of 12 inches and the latter 15 average at a depth of 12 inches. It was decided to allow the clay bed to dry a little and then to retest.

Figure 23 shows the penetrometer readings taken on August 16. As a result of this check, on 23 and 24 August the clay bed was remixed to give cone penetrometer average readings of 20 at 6 inches depth and 35 at 12 inches depth.

Several attempts were made on 25 August to drive the vehicle through the clay bed, the ground clearance being adjusted throughout the test runs. No completely successful run was made on the firmer clay, but the overall performance was better and the vehicle travelled 3/4 of the bed length on two occasions. This was achieved by repeated reversing and progressing in the same ruts. The rut depth was only 9 inches and considerably better traction was obtained than in the July tests. Figure 24 is a complete penetrometer plot of the bed before the tests. Figure 25 shows the penetrometer readings taken after these tests along the course covered by the vehicle. Figure 26 shows the vehicle during a test run in the clay bed.

With the completion of these tests it was determined that no further benefit would be obtained from continuing this part of the test program; therefore, testing was discontinued. Table II shows clay bed test results.

Noise Testing

A noise survey has been completed using equipment manufactured by Bruel & Kjaer, Copenhagen, Denmark, and consisting of the following items:

(1) Type 4135 and 2615 - 1/2-inch microphone plus cathode follower.

(2) Type 2112 - Audio Frequency Spectrometer.

Number Above Line is Reading at Depth of 6 Inches
Number Below Line is Reading at Depth of 12 Inches

N

FEET	Depth	12	24	36	48	60	72	84
21	6 in (above line)	40	27	25	10	10	25	12
21	12 in (below line)	10	10	25	10	20	30	30
18	6 in (above line)	10	18	22	15	12	12	12
18	12 in (below line)	20	20	22	18	20	18	18
15								
12	6 in (above line)	5	5	20	20	15	10	15
12	12 in (below line)	25	25	5	20	15	30	30
9	6 in (above line)	5	5	5	10	12	12	20
9	12 in (below line)	30	18	20	27	35	30	25
6	6 in (above line)	15	12	12	10	22	18	15
6	12 in (below line)	20	12	27	20	20	18	30
3	6 in (above line)	10	12	5	15	12	16	20
3	12 in (below line)	30	25	12	35	22	25	30

Figure 23. Gemini Clay Bed Tests -
Cone Penetrometer Readings August 16, 1965.

Number Above Line is Reading at Depth of 6 Inches
Number Below Line is Reading at Depth of 12 Inches

N

FEET		12	24	36	48	60	72	84
.1	above	20	30	20	20	20	20	20
	below	35	50	45	30	20	45	50
18	above	20	25	30	20	15	20	20
	below	30	40	20	30	25	45	60
15								
12	above	15	10	15	20	20	20	20
	below	35	30	30	40	40	30	50
9	above	20	15	15	20	30	20	20
	below	40	25	27	45	40	40	55
6	above	20	30	20	30	30	35	15
	below	40	30	35	35	50	50	40
3	above	20	22	27	20	35	22	25
	below	40	20	35	40	40	50	30

Figure 24. Gemini Clay Bed Tests -
Cone Penetrometer Readings August 25, 1965.

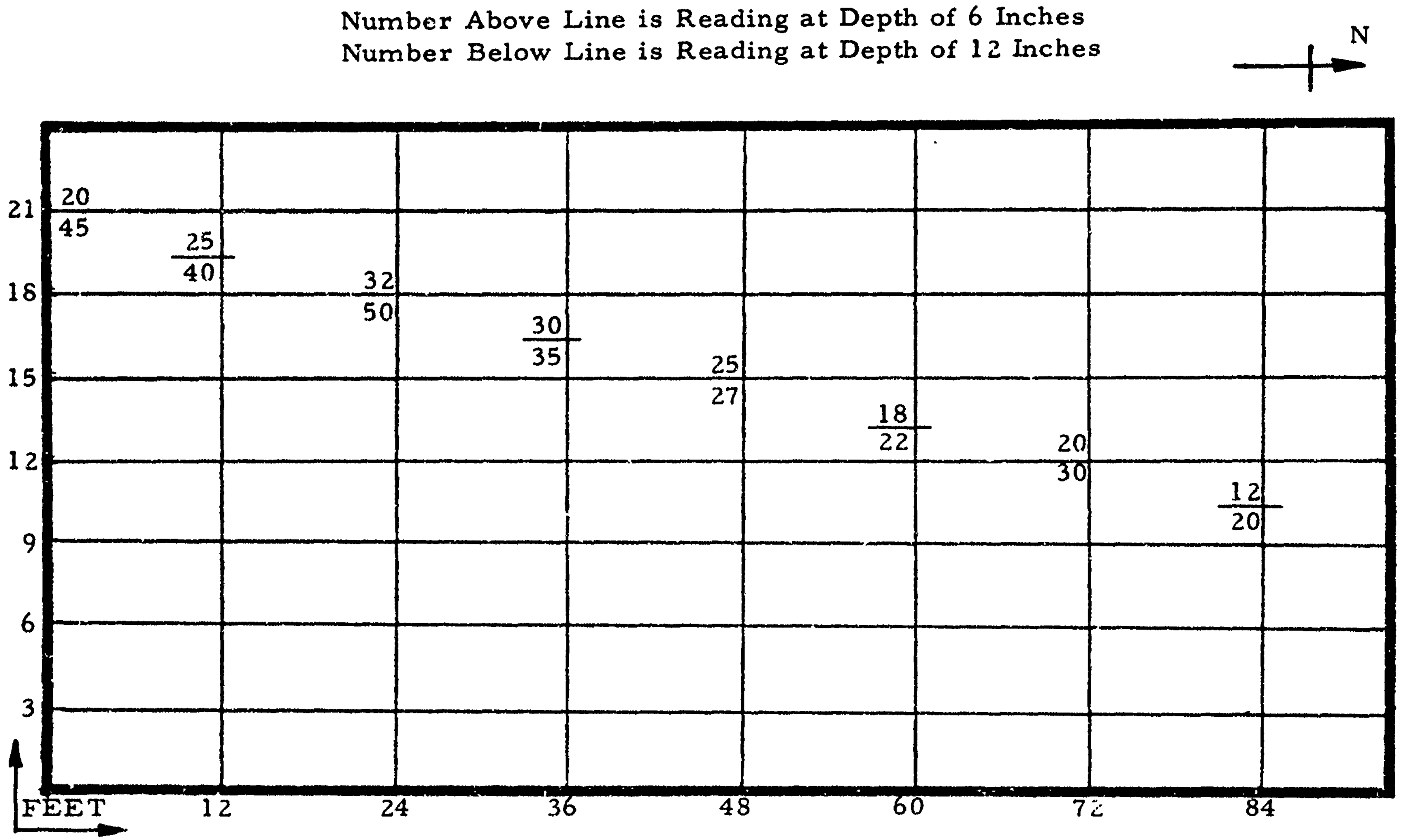


Figure 25. Gemini Clay Bed Tests -
Cone Penetrometer Readings August 25, 1965 (After Test).

Figure 26. Test Vehicle During Clay Bed Test Run.

TABLE II
CLAY BED TEST RESULTS

Date	Engine Speed (r.p.m.)	Fan Total Pressure (P.S.F.)	Base Pressure (P.S.F.)		Wheel Motor Pressure (psi)				
					Front		Rear		
			Rear	Front	Right	Left	Right	Left	
					All Wheel Pressure Traces Off Paper				
Aug 25	5500	103.8	31.6	62.5	1750+	-	-	1900+	Maximum Base Pressure - Run 13, 2nd Attempt
Aug 25	5500	100.2	45.6	77.2	1620	1240	Trace Not Clear	1350	Maximum Base Pressure - Run 13, 3rd Attempt

(3) Type 2305 - Level Recorder.

(4) Type 4220 - Pistonphone Calibrator.

Measurements were obtained over an arc of 100-foot radius from the center of the unit and at angular increments of 30° through the right hand side. The forward measuring position is given as 0°. The ground cover was sparse, trimmed grass on stony, dry sub-soil. Location of the test site was such as to ensure that general free field conditions were obtained.

Throughout the test, the power unit was maintained at 6000 r.p.m. and coupled either to the hydraulic system to give an indicated load of 1000 pounds per square inch, or to the fan. Two recordings were thus obtained at each measuring position. The clearance between the skirt and the ground was 12-1/4 inches at the front and 15-1/2 inches at the rear.

Results are given in Tables V and VI for the two test conditions. A 1/3 octave presentation has been employed from which the octave values have been computed along with the overall sound pressure level. All results are referenced to 2×10^{-4} dynes per square centimeter.

For convenience, the overall sound pressure level (OASPL) for the two test conditions is summarized in the following tabulation.

TABLE III
OVERALL SOUND PRESSURE LEVEL COMPARISON

	Angle (0° front - through right hand arc)						
Condition	0	30	60	90	120	150	180
6000 r.p.m. power to hydraulics	92.7	93.7	95.3	97.1	96.6	94.7	88.4
6000 r.p.m. power to fan	97.1	97.3	101.7	97.9	99.6	97.1	95.5

It will be seen from Tables V and VI that the main difference in the noise spectra for the two test conditions considered occurs in the octave band centered on 4000 cycles per second. This comparison is given in the following tabulation.

TABLE IV
4000 CYCLES PER SECOND COMPARISON

Condition	Angle (0° front - through right hand arc) 0	30	60	90	120	150	180
6000 r.p.m. power to hydraulics	63.4	69.0	72.3	73.6	69.6	68.3	58.4
6000 r.p.m. power to fan	89.1	88.5	91.1	84.6	89.9	82.6	83.6

TABLE V

NOISE MEASUREMENTS AT 100-FOOT RADIUS - 6000 R.P.M. HYDRAULICS ONLY

dBre 2 x 10^{-4} dynes per square centimeter

	Angular Position													
	Front 0°		30°		60°		90°		120°		150°		Back 180°	
C.P.S.	1	2	1	2	1	2	1	2	1	2	1	2	1	2
25	84		80		86		91		84		86		77	
31.5	82	88.2	76	83.4	86	90.4	92	95.1	86	92.8	84	88.7	80	82.6
40	84		79		85		86		91		80		75	
50	86		91		91		90		91		89		81	
63	83	89.3	86	92.4	86	92.8	83	91.6	89	93.6	90	92.9	81	85.5
80	84		79		84		84		84		82		80	
100	81		80		77		80		77		78		78	
125	79	84.3	80	84.2	78	83.3	78	83.8	78	81.8	76	81.5	76	81.1
160	78		78		80		79		76		76		74	
200	73		74		76		78		74		72		70	
250	67	74.8	70	76	73	78.6	76	80.7	74	79.1	72	76	65	71.5
315	67		67		71		72		75		69		60	
400	63		67		67		72		73		69		60	
500	65	69.6	62	69.9	66	71.8	66	73.9	68	74.9	63	70.9	57	63
630	66		65		68		67		67		64		57	
800	69		69		70		67		66		64		64	
1000	66	71.4	71	75.2	71	75.1	73	75.7	70	74.7	65	71.3	64	68.2
1250	63		71		70		71		72		69		62	

1 = 1/3 OCTAVE

2 = FULL OCTAVE

TABLE V (Cont'd)

C.P.S.	Front 0° 1	Front 0° 2	30° 1	30° 2	60° 1	60° 2	90° 1	90° 2	120° 1	120° 2	150° 1	150° 2	Back 180° 1	Back 180° 2
1600	64		70		70		72		71		71		59	
2000	63	68.8	69	74.5	68	75.1	66	76.5	67	73.8	72	75.2	58	62.8
2500	65		70		72		74		68		67		57	
3150	61		65		70		72		66		65		55	
4000	58	63.4	65	69	66	72.3	67	73.6	65	69.6	63	68.3	54	58.4
5000	55		62		65		63		63		62		51	
6300	53		61		63		62		65		58		51	
8000	53	57.8	59	64.1	62	66.6	60	65.3	60	66.8	58	62	51	55.5
10000	53		57		60		59		58		55		50	
12500			54				54		57		52			
16000			52	57.5			54	58	56	60.1	51	56.1		
20000			52				51		51		51			
25000											50			
31500														
OASPL		92.7		93.7		95.3		97.1		96.6		94.7		88.4

1 = 1/3 OCTAVE
2 = FULL OCTAVE

TABLE VI

NOISE MEASUREMENTS AT 100-FOOT RADIUS - 6000 R.P.M. FAN ONLY

dBre 2 x 10^{-4} dynes per square centimeter

C.P.S.	Front 0° 1	Front 0° 2	30° 1	30° 2	60° 1	60° 2	90° 1	90° 2	120° 1	120° 2	150° 1	150° 2	Back 180° 1	Back 180° 2
25	78		76		86		81		88		73			
31.5	85	87	77	83.3	81	89.2	76	86.2	79	90.5	77	81.7		
40	81		81		85		84		86		79		84	
50	89		94		95		94		95		91		86	
63	81	90.7	85	94.8	92	96.9	84	94.7	84	95.7	80	91.6	84	89.1
80	84		83		83		83		85		80		82	
100	88		87		92		84		88		87		90	
125	86	91.3	85	93.2	91	96.8	87	90.3	82	91.5	84	93	86	92.8
160	85		91		93		85		88		91		87	
200	88		85		96		84		86		83		85	
250	83	90	81	87	84	91.6	82	87.1	84	88.9	82	86.6	80	86.4
315	82		78		83		80		81		80		74	
400	77		81		80		80		81		77		70	
500	78	84.9	77	85.2	78	85.1	77	83	76	82.8	76	80.6	72	75.5
630	83		82		82		77		74		74		70	
800	83		82		83		80		77		75		73	
1000	81	86.5	83	87.5	85	88.1	81	85.5	80	84.4	77	82.6	72	76.6
1250	81		83		81		81		81		80		70	

1 = 1/3 OCTAVE
2 = FULL OCTAVE

TABLE VI (Cont'd)

C.P.S.	Front 0° 1	Front 0° 2	30° 1	30° 2	60° 1	60° 2	90° 1	90° 2	120° 1	120° 2	150° 1	150° 2	Back 180° 1	Back 180° 2
1600	82		82		81		81		84		85		69	
2000	82	86.4	81	85.8	81	85.8	77	84.1	80	86	82	86.9	69	74.1
2500	81		80		81		79		77		72		70	
3150	78		78		80		76		77		73		69	
4000	87	89.1	86	88.5	89	91.1	83	84.6	89	89.9	78	82.6	82	83.6
5000	84		84		86		77		81		80		78	
6300	80		79		81		76		79		79		76	
8000	72	81	74	80.7	75	82.6	72	78.2	74	80.6	74	80.7	71	77.7
10000	70		71		74		70		70		71		68	
12500	67		66		70		66		65		67		64	
16000	62	68.5	62	67.8	67	72.2	65	69.1	59	66.3	59	67.9	60	65.9
20000	57		57		62		60		55		55		(56)	
25000	55		54		62				53		52			
31500					60						50			
OASPL		97.1		97.3		101.7		97.9		99.6		97.1		95.5

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13 ABSTRACT

This report presents the further results of testing a full-scale mock-up chassis representative of a 1-ton, amphibious, off-highway, air-transportable vehicle which utilizes air cushion principles to permit mobility in low-bearing terrain.

The test vehicle was modified and subjected to tests in water. A skirt was fitted and the vehicle was tested in prepared clay beds of low cone index and on a level, hard surface. Noise level tests were also carried out. Further work to improve directional control and speed in water and to improve skirt structure is recommended to attain optimum performance.

Unclassified
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14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
AIR CUSHION VEHICLE GROUND EFFECT MACHINE LOW BEARING TERRAIN MOBILITY SKIRTED VEHICLE GEMINI AMPHIBIOUS VEHICLE						

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